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TRANSACTIONS *of the* ILLUMINATING ENGINEERING SOCIETY

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The opinions expressed by authors and contributors to discussions are those of the individuals concerned and are not necessarily those of the Society

Honorary Fellowship

UNDER the Articles of Association of the Society the Council is empowered to elect as an Honorary Fellow any distinguished person whom the Society desires to honour.

It is with great satisfaction the Council records that

His Royal Highness The Duke of Edinburgh, K.G., K.T.

has accepted its invitation to become the first Honorary Fellow of the Society.

In a letter of 16th June, 1959, addressed to the President, Rear-Admiral Sir Christopher Bonham Carter, C.B., wrote: "His Royal Highness The Duke of Edinburgh desires me to tell you that he will be very pleased to become the first Honorary Fellow of The Illuminating Engineering Society and that he is most interested in the extremely useful work being carried out by it."

It is particularly gratifying to the Council and to the Society that this election has taken place in the Golden Jubilee year.

Honorary Membership

At a meeting held on 24th September, 1959, the Council elected to Honorary Membership

Alfred William Beutell

in recognition of his many valuable services to the Society, particularly during its early formative years, and especially of the importance of his original proposals for, and subsequent successful efforts to promote, the development of the Society's lighting code on a rational basis; and of his pioneering the assessment of subjective brightness as well as the utilisation of line-sources of light.

I.E.S. Gold Medal

As already announced in the Transactions, the Council has marked the occasion of the Society's Golden Jubilee by instituting an award to be known as the I.E.S. Gold Medal for outstanding contributions to the advancement of lighting.

It is the unanimous decision of the Council that the first award of the I.E.S. Gold Medal be made to

John William Tudor Walsh, O.B.E., M.A., D.Sc.

Dr. Walsh is an Honorary Member and has twice been President of the Society; he recently completed a distinguished term as President of the International Commission on Illumination. His contributions to photometry and to lighting in general have brought him international recognition as an outstanding leader of the lighting profession of our time.

THE TROTTER-PATERSON MEMORIAL LECTURE

Light and Living Matter

By Professor Sir SOLLY ZUCKERMAN, C.B., F.R.S.

I am very conscious of the fact that whatever contribution I may have made to my own subject I stand up as a stranger in your midst, not having contributed at all to the particular issues in which you are most concerned, electrical engineering, illuminating engineering, and so on. However, rising as I do as a biologist amongst you, I am also very aware of the fact that we owe an enormous amount to your activities, and it gives me very great pleasure indeed to be amongst you to do honour to the memory of your two late distinguished members, Mr. A. P. Trotter and Sir Clifford Paterson.

After I had accepted this invitation I searched through the record of your past speakers to see if I could get any lead from what other biologists had said, and I discovered to my concern that the only one who has been before you previously was Lord Adrian, speaking on a topic peculiar to his particular field of learning, so I got no help. Then, knowing that the interest of your Secretary when he wrote to me was in a lecture which I had already given, and that he wanted me to deal with something in the same field, that is, the influence of light on seasonal processes, I picked up the new book of Sir Stewart Duke-Elder, the famous ophthalmic surgeon, and began by reading his introduction. I should like to read this to indicate what a diffuse problem a biologist confronts when he is working on light and living systems. I quote :

" We begin with a drop of viscid protoplasm the reactions of which we do not understand, and we end lost in the delicacy of the structure of the eye and the intricacies of the ten thousand million cells of the human brain. We begin with photosynthesis in a unicellular plant, or with a change in the viscosity produced by light in the outer layers of the amoeba, and we end with the mystery of human perception. We begin some one or two thousand million years ago in the warm waters of the Archeozoic era and we end with the speculations of tomorrow. And as we travel together tracing the responses of living things to light from the energy liberated by a simple photochemical reaction to the faculty of appreciating and interpreting complex perceptual patterns, neither in fact nor in fiction does a story more fascinating unfold."

That paragraph indicates the difficulty a biologist has in trying to focus on the vast field on which he could touch when he tries to deal with the question of the influence of light on living matter. Living matter is itself extraordinarily difficult to define. In fact, nobody but the most intrepid spirit would attempt to do so today. Living matter as defined by many is the action or behaviour of protein molecules, that being the most general kind of definition which would not exclude any type of behaviour that could be called living, at the same time as it admits none that is not living. In fact, what we really are talking about when we discuss living matter is the control of unstable, self-maintaining and self-reproducing systems which have enduring individuality. That is the nearest one can get to the definition of a living system, which includes ourselves on the one hand, and, say, viruses on the other. Clearly, I have to restrict myself if I am to discuss the influence of light in terms of such a definition.

I can, however, begin by saying that, whatever is admitted within the definition of a living system, and assuming that living systems must be self-regulatory, self-maintaining and self-reproducing, we can accept it that solar energy provided the materials of life and allows for its maintenance. We know about light and photosynthesis, and I will certainly not speak to you about that topic today. You also know that not visible light but ultra-violet and other short-wave radiations are believed to have been responsible, some thousand million years ago or so in the evolution of this planet, for the first creation by chemical synthesis of amino acids—the building bricks of proteins, out of which, of course, come our living systems.

From the very start when living systems were formed we have to assume that the input of energy, whether of light or any other form of energy, was

An edited version of a verbatim transcript of the fifth Trotter–Paterson Memorial Lecture, delivered at the Royal Institution, London, on February 16, 1959.

subject to cyclical variations—diurnal variations on the one hand or seasonal variations on the other—because the spin associated with our planet has presumably always been there, spin, as you know, being a characteristic of every object in the solar system or, for that matter, every object in any celestial system.

Therefore, we have to assume that energy inputs have varied right from the very beginning, and that the impact of light on living systems has operated from the very start. When one discusses living systems one is actually discussing the behaviour of complex protein molecules within an environment in which light and other forms of radiation are an essential part, and without which living systems as such cannot possibly survive.

Thus, in focusing on the topic which I am going to introduce to you, that is, the influence of light upon certain living processes, I first want to remind you of the primacy of chlorophyll, of the formation of chlorophyll and of the part played by photosynthesis in the storage of energy.

The second thing of which I want to remind you is that the green plant, whether it be herbage growing on the earth or plankton growing in the sea, is basic to all living systems, and that life does not occur in any isolation. There is a living food chain all the time, one thing being dependent on another, all this being epitomised in the statement that "all flesh is grass and all fish is diatom." What we have to assume is that the seasonal variation in the trapping of energy by the land plant or by the plankton of the sea—they make up the pastures of the sea—is the background of the annual cycle of life.

The phases of the life cycle of every creature synchronise with seasonal changes in the environment and also the diurnal variations in light input. The majority of systems, nearly a million species—and I am not now only talking about primitive systems like viruses and bacteria but also about those things we would call animals—are what are called poikilothermic; they are creatures whose temperature is determined by the temperature around them, and whose reactions are immediately fixed by the variations of heat input, light input and so on. Creatures like frogs, for example, belong to the world of poikilothermic animals. There are only about twenty thousand species like ourselves that are described as homoeothermic, that is to say, partly emancipated from their environment. Our temperature remains more or less constant within a very narrow range, somewhere between 96° and 104° or 105°F with an average temperature of about 98.4°. We all know that if our temperature rises beyond these limits of tolerance, or falls below, life has to cease simply because the normal range happens to be the only one within which human proteins can survive; above that range, as it were, protein changes much in the same way as it does when an egg is boiled. We are able as homoeothermic creatures to regulate our internal temperature by losing heat at the surface and by moving to cooler environments if there is any danger of our becoming overheated.

One of the best examples I know of a highly developed creature which is absolutely determined in its way of life by seasonal variations in light input and by seasonal variations in the amount of photosynthesis that takes place is the basking shark. This is an animal not many of us have seen, although it exists in our waters. It is enormously big, weighing some three to four tons, and cruises along very sedately, filtering through a vast comb-like mechanism in the front of its mouth the plankton of the sea, those unicellular green organisms, not plants but little animals, which also trap the sun's energy through the process of photosynthesis. This vast basking shark goes along very, very slowly, at three or four knots, filtering the sea almost like soup, and catching the plankton on what are called its gill-rakes. In October when the autumn begins and the amount of sun radiation is declining, the rate of photosynthesis starts declining, and not enough plankton is formed to satisfy this vast beast. If it went on cruising in order to get plankton it would be losing far more energy than it gained, so the moment the energy balance becomes negative the creature, as has very recently been discovered, sinks to the bottom of the sea somewhere between the Irish and the Scottish coast, sheds its rakes and hibernates. It comes up again in the following spring with a new set of gill-rakes to deal with the plankton that will then be before it.

There you have a most impressive instance of the way seasonal variations in the input of radiant energy from the sun and light—light is the critical thing here—determine firstly the growth of plankton, the material which is trapping the sun's energy and turning it into useful carbohydrate, protein and fat, and secondly the behaviour of a vast animal which is absolutely determined by the facts of this very simple story I have told you.

It provides only one illustration—although it is a very striking one—of the adaptations of animals to seasonal variations in light input. Seasonal variations in secondary sexual characteristics are also controlled by light, for example, the growth of antlers in certain types of stags, though not all. Hibernation is determined in the same way, and

so is the migration of birds. I shall be dealing with that in a moment. There are some creatures which are prevented from hibernating or migrating and which merely have to tolerate the bad conditions of winter and starve their way through the season in which there is no light, waiting until the grass grows again the following spring. The black-faced sheep of the Highlands is one of the best local examples. No doubt these animals would migrate to the south if they were not prevented from doing so, but during the winter these sheep really suffer from acute starvation, to the extent that the pregnant ewe will deplete her own reserves of calcium and phosphorus in building up the new bones of the young she may be carrying.

I am going to talk, as I said, about the control exercised by light on one seasonal variation which we call the breeding season. The breeding seasons of animals, such as sheep or ferrets, and that of almost any creature you can think about, as well as of plants and flowers, are all modulated by external factors, but they are ultimately determined through hereditary mechanisms. Some sheep may breed twice in a year, but the majority breed only once. The polar bear in the northern hemisphere will have its young usually in the month of November, and never at any other time. It may possibly do so during the last week in October, or perhaps the first week in December, if you take the records of a hundred years, but no polar bear has ever dropped its young in August and no polar bear, one may hazard a guess, ever will.

Seasonal behaviour of that sort is immediately transformed when you remove an animal from one hemisphere to another. No polar bear kept in a menagerie in Australia will ever have its young in November ; it will have it in the corresponding season of the southern hemisphere. So, too, if one transfers species with restricted breeding seasons from the southern hemisphere to the northern, after a short time, usually in the first season, their internal clockwork is geared to the circumstances in which they find themselves. There are a few exceptions, and the exceptions, needless to say, will be disastrous. If one were to transfer a species to a different set of seasons and it did not become acclimatised, that particular species would disappear.

There are some creatures which live on the equator, and they form a very interesting object of study because there is extraordinarily little seasonal variation there. Let us say that if you move a species two degrees north or south, you may find that the creature's inherent cycle of breeding is unaffected. Environments are never completely constant, however, and though light may be the same on the equator at all times rainfall is not, and one discovers there are yet other factors modulating an inherent rhythm.

I have recently been told by a friend who has just come back from investigating the behaviour of swifts in caves in Borneo—again, I think it is two degrees north of the equator—that in the same cave he found three related species of swift. In Borneo swifts are very important because they provide the birds' nests for the bird's-nest soup, and are therefore collected seriously as a native industry. There are some swifts living in these dark caves which have a very, very restricted breeding season ; everything happens, as it were, in one month of the year. Another species has a slightly more prolonged season of breeding, say, three to four months, and the third is apparently not restricted to any time of the year. The same thing happens with bats living there. One day every female bat that is collected will have a young bat clinging to her, but a week later the collectors will not find a single female bat with her young. They have all fluttered off on their own.

Thus some very curious things happen under apparently constant conditions, but in the cases where one is not certain about the changes in the quality of the light or the duration of the light there are other factors which are concerned : a food supply that is varying, rainfall that is varying, humidity that is varying and so on. While light is, in fact, the most important modulating factor for inherent reproductive rhythms, it is not the only one ; it happens to be the one which we are able to study in this country and therefore it is the one which I propose to deal with now in the sense that, while light is the source of all the energy on which the world we know exists, light is also the signal for its utilisation.

The story I am going to tell you begins with the simple fact of migration, which has been investigated and observed by naturalists for hundreds of years. The swallow appears and disappears ; birds have their summer breeding grounds, as well as their wintering grounds. In different parts of the world birds of the same species will vary in their migratory behaviour. The Arctic tern will come to this country to spend the summer and will go even farther south. Some terns will come up all the way from the Antarctic. Vast migrations are thus undertaken by birds. This has always been known, but the fact that most of these migrations are triggered by variations in the input of light was discovered only in the early 'twenties by a Canadian zoologist, Professor Rowan, who died quite recently. He did his work on the

Canadian bunting, a bird whose vernacular name is the junco. He caged some juncos in big outdoor aviaries during the summer in his part of British Columbia, and when he released these caged birds from the aviary after the main migration of the juncos had started, they never moved at all ; they stayed where they were and never made any attempt to migrate. He dissected the birds and found that those that departed normally on migration did so after the end of breeding activities —British Columbia is the natural breeding ground of the junco—but just before the annual regression or atrophy of the reproductive organs, the testes and ovaries, had set in. If the birds were retained in the outdoor aviaries until regression had begun they would not migrate afterwards. The motive power, in other words, of the migratory instinct was dependent on the state of the reproductive organs.

The question arose, what was it that made the gonads regress in size towards the end of the breeding season or become functional and increase in size at its beginning ? Professor Rowan did a very simple experiment : he illuminated some aviaries and found that those birds' ovaries, or testes in the case of the male, became quickly re-activated if the experiment was done after the breeding season had ceased. He then let these birds go, with their reproductive organs in a functional state. The motive element was there and they usually disappeared, although from that moment on the course of their migration was disturbed.

This therefore showed that light was the functional stimulus both for bringing reproductive organs into an active condition and for their regression ; the daily decrease in the amount of the light was the circumstance which led to the atrophy of the reproductive organs. At that time, strange as it may seem, people were not illuminating hen-houses in order to spread the egg-laying season of the birds, as everybody does today. Rowan's experiments came as a very considerable surprise, and people then started to look around. It transpired that many people who were not physiologists or zoologists had been doing this sort of thing for generations. For example, egg-laying under constant conditions of illumination is apparently an old Spanish practice ; similarly, people who keep song birds, particularly the Japanese, knew what it takes to make the birds sing better, and it usually takes light.

Let me illustrate some of these relationships. To the best of my knowledge, the figures shown in Fig. 1 are based upon so-called national statistics. The line at the top shows what happens under

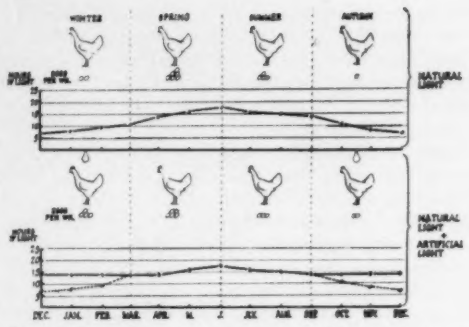

Fig. 1. Effect of seasonal and artificial changes of light upon egg production.

conditions of natural illumination. Most eggs are laid in the spring and early summer ; the numbers then fall off in the autumn and start to rise again in the winter. The same thing happens in mammals which are seasonal breeders. The onset of reproductive activity, the re-activation of the reproductive organs, occurs in what one would normally take to be the depth of winter. Below, the heavy, dark line shows the distribution of egg-laying under conditions of illumination, the dotted line repeating what is shown above, the ordinary distribution. That simple fact is the basis of a vast industry. Presumably there would be a revolution if it did not go on in that way now. That is how we get our eggs. I must add that you do not get any more eggs that way ; you merely accelerate the production of eggs by the ovaries of the bird.

I remember in the late 'twenties or early 'thirties Rowan came over here from British Columbia to study the effect of the illuminations, the advertising lighting, in Trafalgar Square and Piccadilly Circus on the starlings. As a control he used starlings he collected in a wood near Oxford. On alternate nights he collected birds from Oxford and from London, and he found that the birds he collected in London—by means of a lot of snaring and dangerous work on the parapets of the National Gallery, I recall—had active reproductive organs at a time when those of the birds from the country were completely atrophied and non-functional. At that time, for an unfortunate reason, Rowan had started tracking an idea which proved to be false, that what was involved in stimulating the gonads, that is to say, the ovaries or the testes of an animal, was not light but activity, and that creatures were more active in light and that was the significant factor in this particular response. That idea of his was wrong.

The creature we have worked on mostly ourselves is the ferret. Fig. 2 shows the onset of the breeding season in ferrets. The upper curve indicates the time of the normal onset, somewhere in March, April and May, and the animal becomes non-reproductive some time towards the end of August or the beginning of September. For six months of the year ferrets cannot breed; they do not hibernate but they cannot breed and during the course of the other six months they are in a breeding condition. If one illuminates a ferret in the simplest conceivable way, as shown in the lower curve, by keeping a light on for, say, six hours after darkness from, perhaps, October onwards, one finds that within about six weeks the animal becomes reproductively active again and that it can breed. We have had ferrets giving birth in December and January as opposed to waiting until May or June. It is entirely a function of light, as I will explain in a minute.

What we have discovered is that a very little light is sufficient. Normally we operate rather crudely with unmeasured quantities of light, but a member of my staff has recently been trying to calibrate the input that is necessary and he has not got down to the threshold yet. He has determined that two foot-candles will cause that effect in a ferret, and I am hoping that he will be able to get a more precise measurement of the threshold this coming season. It is an extraordinarily little amount that is needed.

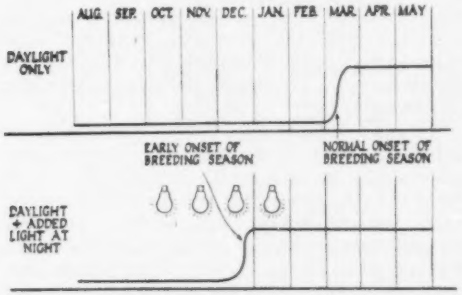

Fig. 2. Effect of additional artificial light on breeding season in ferrets.

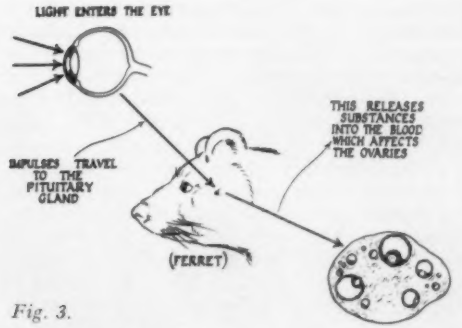
LIGHT ENTERS THE EYE
IMPULSES TRAVEL TO THE PITUITARY GLAND
THIS RELEASES SUBSTANCES INTO THE BLOOD WHICH AFFECTS THE OVARIES
(FERRET)

Fig. 3.

A blind ferret does not react in the same way. The blind ferret will assume a rhythm which is the usual rhythm of reproduction. Each year it will come into heat and breeding condition at about the end of March or in April, and it will stay in that condition until the end of August. You can expose it to as much light as you like and it does not respond. There is no acceleration of the breeding season. In other words, light in some way is acting upon the retina through the eye and is influencing the creature's physiological mechanisms. The problem we have been investigating, and which we have failed to solve after years and years of work, is the way the impulse is transmitted through the retina, through the eyeballs, so that it influences the gonads.

Fig. 3 is a schematic diagram to show you what I mean. Light is entering the eye in the upper left-hand corner. In some way that light must get to a little gland at the base of the brain called the pituitary gland. We know that because if the pituitary gland is not there, if it is removed and the animal is still receiving visual impulses through its retina, along its optic nerves, again nothing happens. The other thing we know is that the reaction will not occur if the ovary shown in the lower right-hand corner is removed from the body. In other words, there are three essential links in this response: light enters the eye, so that the eye and the optic nerves are essential; next, the pituitary gland at the base of the brain; and last, the ovaries in the case of the female or the testes in the case of the male. One can prove that each of those is an essential part in the process. We know what the link is between the pituitary gland at the base of the brain and the gonads, but we do not know what is the nature of the link between the eye and the pituitary gland.

That between the pituitary and the gonads is what is called a hormonal link. The pituitary gland is a minute bit of specialised tissue. The human pituitary gland, for example, is smaller in size than the nail of one's thumb, but it produces a series of chemical secretions, protein substances, which immediately get into the blood stream and affect practically every other endocrine, that is to say, hormone-producing organ in the body. If the pituitary gland is removed the chemical it

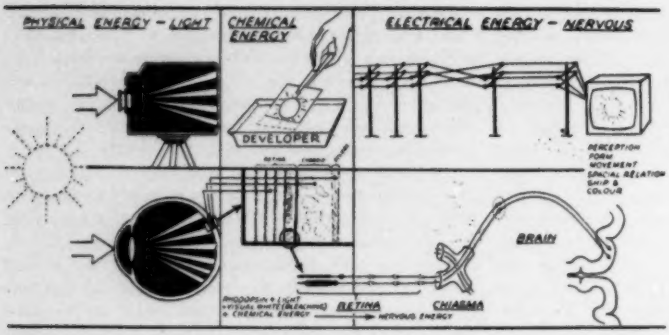

Fig. 4.

otherwise produces is also removed and no longer acts on the gonads, and as a result the gonads involute or atrophy, and cease to function. We know this from the results of numerous experiments, and we are not far from the day when we shall know precisely the chemical nature of the substance produced by the pituitary which has this extraordinary, dominating effect on the gonads. One can get extracts of pituitary tissue and inject them into the ferret or any other animal—this is done clinically in human beings —in order to activate the ovaries or the testes. The link between those two, therefore, is a hormonal, chemical one.

However, the link between the eye and the pituitary is certainly not a straightforward chemical one. Fig. 4 indicates schematically what the problem is. The upper part is a rather naive representation of light going into a camera on to an active chemical surface which is developed and then transmitted—in the same way as your speeches were, I understand, at the Jubilee Dinner —so that you get a picture on some sort of screen. Precisely the same thing happens when light falls on the eyeball. Light comes in through the lens system on to the retina, where a chemical reaction takes place. The grid system shown in the central part of the picture is meant to be an enlarged schematic drawing of the retina. There, certain chemical changes take place within certain sensitive cells, the cones and the rods of the retina. Those chemical changes are transformed within the same cells into an electrical impulse, nobody knows just how at the moment, and that impulse is then conveyed to the brain, as can be seen on the lower right-hand side of the picture.

We know that these electrical changes take place in the brain, and to which parts of the brain it is that these impulses are projected. The next figure (5) shows, again schematically, what are called the brain-waves, which are now measured in hospitals in the same way as one takes the blood pressure—it has become as standard a procedure as that—in order to find out, for example, about people in whom a tumour or some other type of cerebral disturbance is suspected. The object of the figure is merely to show the record of impulses which are being fired off by the brain substance when the eyes are shut, and this is represented by the wave-like motion at the very top. When we open our eyes something happens which cuts down the electrical activity, and when we close them once again those electrical impulses are discharged. I mention this only because it is part of the story.

We know then about these electrical impulses and to which part of the brain they are fired, but how do they get to the pituitary gland? Fig. 6 shows the pituitary gland, and the so-called optic tract, along which visual impulses from the eyes are conducted towards the hinder part of the brain; this region is known as the visual cortex, and represents the first and most important part of the cerebrum which is affected by light impulses. But our problem is to find out how the impulses get to a specialised structure to which the pituitary gland is attached. It so happens that while there are millions of cells in the brain, cells which are aggregated in different groups in different ways, connected by thousands and thousands of nerve tracts, we simply do not know which nerve tracts connect the visual area with the part of the brain that lies just above the pituitary and is known as the hypothalamus—a term I shall have to refer to repeatedly from now on. The hypothalamus is a minute part of the brain placed above the pituitary gland and it is concerned in the regulation of most of the visceral functions of the body. For example, if there is any trouble in the hypothalamic region the regulation of sleep and meta-

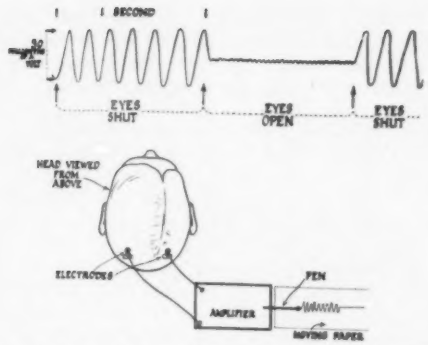

Fig. 5. Effect of opening eyes on electrical activity of the occipital region of the human brain recorded from the back of the head. Activity of the brain is associated with minute waves of electrical currents which can be detected by electrodes placed lightly on the surface of the scalp, amplified and recorded on moving paper. Closing the eyes increases, while opening the eyes decreases, the size and regularity of the waves.

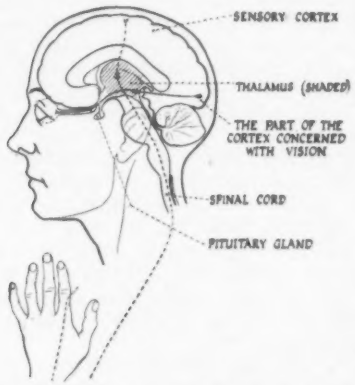

Fig. 6. The nerve fibres along which electrical impulses of sensation are carried, relay in the cells of a deep laying part of the brain called the thalamus. From the thalamus other impulses pass to the cells of the various areas of the outer layer of the brain (cortex) which are concerned with these sensations. The part of the cortex concerned with sight lies towards the back of the brain, that for touch and pain towards the crown.

bolic functions are likely to be upset. I do not mean just plain, straightforward metabolism in the sense of becoming fatter than one normally is, but one's control of water and one's electrolyte metabolism would go wrong. That is the vital part of the brain concerned with these physical functions, and the pituitary, which appears to be suspended from the hypothalamus, is the gland which controls the gonads.

We have done many experiments to try to track a possible pathway of light impulses to that particular area of the brain, and all of them have failed. Whatever one tries to do by way of interrupting the visual pathway and possible pathways between the visual cortex and the hypothalamus, the reaction to light in the ferret still persists. In other words, we cannot cut whatever " wires " there are which connect those regions.

The last figure (7) is a median section of the ferret brain and demonstrates that region with which I have to deal for the rest of my talk. At

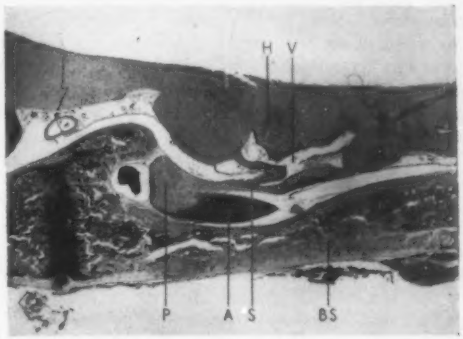

Fig. 7.

the bottom is the bone forming the base of the skull (BS). Above it lies the pituitary gland, and its stalk (S) which suspends it from the hypothalamus (H) at the base of the brain. The space shown immediately above it is a real one and is known as the third ventricle (V).

The pituitary gland shown in the picture is greatly magnified ; in fact, in the ferret the gland is not even 2 mm. across. The front part of it, or anterior lobe (A), is very dark, and that at the back, the posterior lobe (P), is light-coloured. This light-coloured part is connected with the brain ; the anterior lobe is not connected with it at all. Even the posterior part is connected with the brain only by a mass of nerve fibres—well over a hundred thousand in the case of the human brain —and each fibre has its nerve cell in the hypothalamus, above. It so happens that these nervous connections do not reach the front part of the pituitary which is the one concerned in the seasonal response to light. Only it, the anterior

lobe, produces the hormone which stimulates the gonads as a result of the translation of light through the retina, not the part attached to the brain.

Therefore one starts out with the rather incredible problem that even if one could track those light and visual impulses from the eyes towards the rear of the brain, one would then have to follow the light impulses down to the hypothalamus. Even if you assumed that you ought to be able to do this, and that we have only failed so far because of technical incompetence or because we have not thought of the right experiment, you nevertheless come up against a blank wall so far as the nervous transformation of energy is concerned, because the part of the pituitary gland which is connected with the brain is not the one that produces the substance with which we are concerned. Yet it has some very important functions of its own. If, for example, the slender pituitary stalk is cut, along which nerve fibres are passing, the whole of the posterior part of the pituitary will shrivel up. When it does so, some amazing changes occur in the body, the most important of them being that the body is no longer able to control its water metabolism.

The hypothesis on which many workers have been working for some time is that in the same way as there is a translation of a chemical change into an electrical impulse in the retina as a result of the impact of light, so, too, there may be a similar but opposite translation in the hypothalamus, a translation of an electrical impulse, so to speak, into a chemical change. It is assumed that while there are no, as it were, electrical connections between the brain and the black part of the pituitary, there is a system of vessels which is able to pick up certain chemicals produced within the nerve cells of the hypothalamus and carry them selectively down through a very specialised system of blood channels into the anterior part of the pituitary. That is the hypothesis on which we have been working for some considerable time. To my way of thinking, I am afraid, it is very much of an exploded hypothesis. Two things at least are necessary before one can start testing the hypothesis. The first is that since we are dealing with infinitesimal quantities of chemical substances, if you are going to assume a direct effect of these substances on specific parts of the pituitary, you must also have an absolutely specific set of channels to carry the molecules down. But it is now quite certain that even if there is a special set of vessels connecting the base of the brain to the anterior lobe of the pituitary—the reason those vessels are all black in the figure is because they are filled with Indian ink—nevertheless there are very free connections among the vessels between the anterior and posterior lobe. In other words, you are not dealing with separate channels down which molecules can go and cause specific reactions.

The second thing which one would have to believe is that if one stimulated the hypothalamic area of the brain, say, because one assumed it would bring about changes in the black part of the pituitary gland—and it does, because with electrical stimulation one can produce the characteristic changes in the gonads—these effects of stimulation are again not specific because one can similarly interfere in other parts of the brain and precisely the same thing happens. The critical test of the idea that light comes into the retina, passes along the optic nerves, becomes relayed to the visual cortex and from there in some unknown way to the hypothalamic region, and so on indirectly to the pituitary gland would be that the response could not occur if one had complete separation between the pituitary and the base of the brain. This one could do by severing all blood vessels with a minute ophthalmological knife and preventing their re-formation by making a complete mechanical barrier between the pituitary and the base of the brain. If you tried that—and it can be done experimentally, although it is far from easy—and then exposed the animal to light, say, in November, when it ought to be in a non-breeding condition, the light would obviously enter the retina, and follow the same indirect pathway to the hypothalamus, but you would find that even though there is no way for it to enter the front part of the pituitary gland, the stimulus, whether it is in the form of electrical energy or chemical energy, gets there just the same because such an animal's gonads will still respond to light!

That is the unfortunate end to my story, but it gives you perhaps some idea of the difficulties which are involved in trying to understand the very potent effect which light has upon physiological mechanisms and in tracking down the pathways of light in the same way as you can track down the pathways by which this light is now being cast in front of me by this bulb. What we are trying to understand is perhaps very much more difficult to appreciate than the problems you have to deal with in your professional capacities, although I fully realise that what you do is difficult enough. However, I can only hope that when we have discovered which way light is able to jump across barriers which are there and barriers which are not there, and to transform

itself into one form of energy and then into another, we may have something to contribute to your Society.

Vote of Thanks

Professor W. D. WRIGHT: Mr. President, Sir Solly Zuckerman, Ladies and Gentlemen, I am very happy indeed to have this opportunity of proposing the vote of thanks to our lecturer this evening. You will know that this is a very important year for the Society; we are celebrating fifty years in which our own Society has made a very real contribution to the health and well-being of the world in which we live.

This is an important year in other ways. We are meeting in Brussels internationally for the Meeting of the International Commission on Illumination, and we have the honour and privilege in this Society of having in our midst the President of the International Commission, Dr. Walsh. We are also holding a number of other Jubilee Celebrations 1959 is in fact a red-letter year for the I.E.S., and it seems to me that this lecture which we have heard tonight fits in very well with that pattern and the high level at which we are operating this year. We do thank you, Sir Solly, very much for giving us such a fine lecture.

I think the title which you have chosen, "Light and Living Matter," is extraordinarily apt for such a Society. We deal with light and we deal with living matter—very complicated living matter, which is not at all easy to handle, and you have given us a very inspiring lead. There were a number of points in your lecture which I might comment on, one or two quite personal ones. My first industrial job was in America with Westinghouse in 1929. I was really there to deal with problems in television, but the director of research was interested in farming and breeding hens, and one of the first things I was asked to do was to advise him on providing additonal artificial lighting for his hens in order to increase his egg production. I suppose 1929 was a fairly early date for this sort of thing to be done.

I am not sure that one or two of your remarks and figures would be very popular with lighting manufacturers and the lighting industry! A number of eyebrows were raised when you said that only two foot-candles were necessary for the ferret; you probably noticed that. One of the things industrialists in this field have to do is to persuade manufacturers that light is really necessary and that a lot of light is necessary for high-level production. The hard-boiled manufacturer has some interest in the headaches from which his operatives may be suffering, but the thing which really convinces him is that if he has more light, then his output rises. I do not know if our consultants have thought of quoting what happens to hens when you give them more light, but this is something we must bear in mind.

Another thought occurred to me that some discussion is going on about the levels of lighting which are recommended in this country and in America. One must not let one's thoughts dwell too much on the relation between this subject and your lecture, but it is curious that the Americans seem to require so much more light than we do!

Your lecture this evening has been quite a thrilling experience. One of the really outstanding experiences I had last year was reading a book by an American anthropologist, Loren Eiseley, called The Immense Journey, in which I know you are mentioned and quoted, Sir Solly. He gave a very vivid illustration of the importance which water plays in living organisms, and the book made a great impression on me. I feel that tonight you have shown what a very vital part light plays in life. We have greatly appreciated the lecture and the compliment you have paid us in dealing with the subject in a very serious and sophisticated manner. I have not felt at all that you have been talking down to us, and although you have been dealing with difficult matters you have put them in very straightforward, simple language.

I have very much pleasure indeed in proposing this vote of thanks.

Mr. D. L. TABRAHAM: Mr. President, Ladies and Gentlemen, a week ago tonight, on the occasion of our Golden Jubilee dinner, Sir Charles Wheeler, the President of the Royal Academy, suggested that perhaps we were not as grateful as we should be for the gifts of light and of colour, which he described as the progeny of light. In inviting us to imagine a world without colour he reminded us that light and colour are responsible for so much of the joy of living. Sir Solly Zuckerman has shown us tonight that, in fact, light bears very considerable responsibility for the fact that we live at all, and he has described some of the effects of light on living organisms. It seems to me, therefore, that we members of this Society, in this notable week of our Jubilee year, have had our responsibilities impressed upon us in no uncertain way by artist and by scientist and that alone is something for which we should be very grateful, remembering that those responsibilities embrace not only the provision of good sources of artificial light but also the proper use of light in preserving eyesight, in enabling us to work well and efficiently,

in creating atmosphere and in adding happiness and beauty to the lives of our fellow men.

You, Mr. President, referred in your opening remarks to the eminent people who have given this lecture in previous years—great names in physics, physiology, astronomy. You also referred to the achievements of our speaker tonight; you did so briefly for as you said to recall them in detail and to describe adequately the distinguished services rendered to many important organisations by Sir Solly Zuckerman would indeed take a long time. However, we do know that one of his gifts is that of clear exposition and attractive presentation of a very complicated subject and this has made listening to him this evening not only a privilege but a pleasure and an inspiration as well. I am sure he will forgive me if I say that at the beginning of this talk I was reminded of a very young friend of mine who was followed home from school last term by a report which, to say the least of it, did him no credit at all. His father who was very upset expressed his feeling with some candour and at considerable length, but when he had finished the boy asked quite cheerfully, "Well, father, would you put it down to environment or heredity?" I think I could answer that question with more confidence having heard Sir Solly Zuckerman tonight.

We always appreciate lectures which, to many of us, are on marginal aspects of our day-to-day work, not only because they are remote from the way we spend most of our time and from the subjects we usually discuss at our meetings, but also I think because they do stimulate fresh thinking, which can cause us to raise our sights and to look for new targets in our normal work. That is something that we should do continually in dealing with the subject of lighting with its unlimited horizons; and I have, therefore, the greatest pleasure, Sir, in seconding the vote of thanks to Sir Solly Zuckerman which was proposed by Professor Wright.

UDC 628.972

The Permanent Supplementary Artificial Lighting of Interiors

By R. G. HOPKINSON, Ph.D. (*Fellow*) and J. LONGMORE (*Member*)

Summary

Since the opening of the half-century, new ideas on building have been visible everywhere. These visible changes are the expression of a revolution in building construction methods and in the economic picture of building. Rising costs demand a more efficient use to be made of available space, which in turn means deeper rooms with lower ceilings. Daylight is not free, it must be paid for in terms of cubic feet of space, square feet of glass, and loss of heat. In fact the provision of adequate daylight to the back of a deep room in the quantity now considered adequate by modern standards would lead to such an amount of glazing that not only would the cost be prohibitive, but the discomfort from sky glare would be unacceptable.

It is shown that permanent supplementary lighting can be used to overcome these difficulties. The cost of installing, running and maintaining such lighting is offset by the reduced costs of building and maintenance and by a more efficient use of the available site.

Experimental studies have been made to determine the levels of supplementary lighting that are necessary for a good integration of daylight and artificial light. The results of these studies are applied to a new technical college and to an agricultural research laboratory.

Man's need of natural light for his well-being was unquestioned until quite recently. The man-made environment is, however, now an accomplished fact, especially in North America, where it is sometimes claimed that better and more comfortable lighting can be created artificially than by daylight.

This paper does not start from such a premise. Throughout it is taken for granted that access to natural daylight is desirable and necessary. On the other hand, it is realised that the high levels of illumination shown to be necessary for the efficient performance of work under present-day conditions cannot always be provided by natural light without introducing attendant discomforts from excessive sky glare. The best solution may then be a proper integration of permanent supplementary artificial lighting with good natural lighting. The daylight should still be dominant, and should determine the character of the building. The artificial lighting should be subordinate to the daylight.

Experience in these problems is more extensive in the United States of America than it is here, but even there no systematic study of the problem seems to have been attempted. There the habit has been more to exclude the daylight by blinds, or by building in only a small view window from the start, relying for the working illumination entirely on the artificial lighting. Daylight is regarded as bothersome, best left out.

Nevertheless it seems to be accepted, even in the U.S.A., that completely windowless workplaces may cause a sense of deprivation unless very carefully handled. However, rooms with a view and some access to daylight cause no complaint. North Americans, we know, are attuned by their severe climate to an artificial environment, but there seems evidence that for economic reasons we also in due course will learn to live in more of a man-made environment than we do now.

This study was precipitated by a building problem, and it still remains a building rather than a lighting problem. There is interest for the lighting engineer, however, especially as the solution was arrived at by brightness thinking rather than by illumination thinking.

Greater demands are now made on the architect to make more efficient use of the available site (especially in densely built up areas) and to get more usable space from the available floor area of the building. To meet these needs he must build more compactly, and in particular he must build deeper rooms with lower ceilings, effecting considerable economies in building costs. For example, Fig. 1 shows the relationship found between building costs and ceiling height for a group of research laboratories studied by the

The Authors are with the Building Research Station of the Department of Scientific and Industrial Research. The manuscript of the paper was first received on November 21, 1958, and in revised form on February 13, 1959. The paper was presented at a meeting of the Society in London on March 10, 1959.

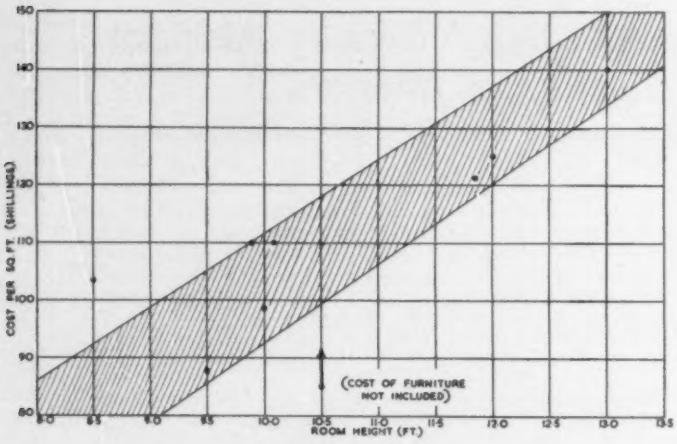

Fig. 1. Variation with room height of cost per sq. ft. (excluding external works).

Division for Architectural Studies of the Nuffield Foundation, with whom the Building Research Station has been co-operating in the present researches. It shows clearly the economic advantages gained from low ceilings.

In parallel with these demands on the architect, the people who will occupy the building are no longer content with the levels of lighting customary only ten or fifteen years ago. The increases in artificial lighting levels have in fact set new standards of demand for daylight. Work people who can enjoy 50 lm/ft² at the touch of a switch are not going to strain to see in 5 lm/ft² of daylight. It therefore becomes next to impossible to provide acceptable levels of daylight in these new designs of interior. If the levels are achieved, it can only be at the cost of excessive sky glare, excessive solar heat gain in summer, and serious heat loss in winter. The solution clearly lies with combined daylight and artificial light, or with the American approach in which daylight is all but excluded altogether. The extra cost of installing and running the lighting should be more than offset by the reduced costs of construction and maintenance and by the more economical use of the site.

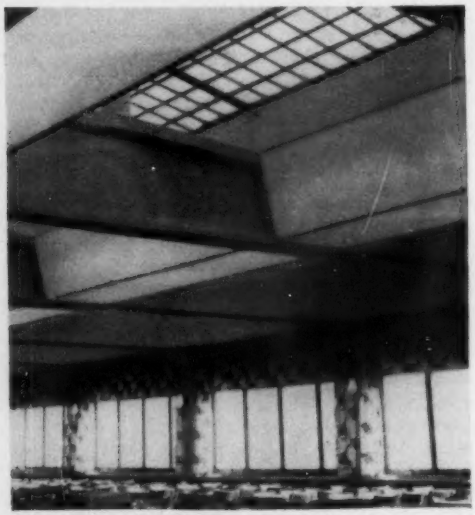

Fig. 2. The roof lighting in the dining-room of the Max Sievert cable factory at Sundbyberg near Stockholm is supplemented by fluorescent lighting which blends well with the daylight.

If the idea of permanent supplementary lighting is to be a success, it must be demonstrably better than the total exclusion of daylight after the American pattern. Supplementary lighting will require more engineering skill and care in design, even if it is not more costly. It must be conceived and fully integrated with the design of the building, not put in as an afterthought to rescue a bad building Fig. 2 shows the dining room of the new building for the Max Sievert cable factory at Sundbyberg, near Stockholm, in which the permanent supplementary lighting is so linked to the daylighting from the roof lanterns that a complete blend, aesthetically and technically, is achieved. It is this blend which must be constantly in mind when the principles to be evolved in this paper are applied.

(1) The Lighting Problem

In North Western Europe it is customary to base the daylighting design of buildings in terms of the ratio of the interior to the exterior light. This is known as the *Daylight Factor** and it can be shown to be chiefly dependent on the size and position of the windows relative to the position of measurement indoors. Since the level of exterior daylight varies from hour to hour, with the seasons and the weather, the daylight factor gives only a rough guide to the actual level of illumination in the room at any given time. In an attempt to strike a mean of these variables, it is customary also to base designs on a C.I.E. Standard Overcast Sky, giving a total exterior illumination of 500 lm/ft². This value was chosen because it corresponds both to a deep blue sky and to an average overcast sky. When a room has been scheduled to give a minimum level of working illumination, say 10 lm/ft² demanded by Statutory Building Regulations, for example, the minimum Daylight Factor in that room is found simply by relating this level of illumination to that of the Standard Sky.

Thus, required Daylight Factor

$$= \frac{\text{Statutory minimum illumination}}{\text{Standard sky illumination}}$$

$$= \frac{10}{500} \times 100 \text{ per cent}$$

$$= 2 \text{ per cent.}$$

The working illumination will be greater than 10 lm/ft² for a great part of the year, when the outdoor light is more than that of the Standard Sky, and it will be less than 10 lm/ft² during part of the working day in winter, spring and autumn, and, of course in bad weather at any time of the year. On such occasions there is need for supplementary light, but the real problem arises when it is either impossible to install sufficient glazed area to achieve the necessary daylight factor, or, if such glazing is installed, the sky glare is so excessive that complaints of unacceptable discomfort are made.

If we leave out the glare problem for the moment, and concentrate on the provision of necessary levels of working illumination, there is one method of determining the amount of supplementary light which will appeal in its engineering simplicity. If E lm/ft² is the necessary level of working illumination, determined by Regulation or by the I.E.S. Code, and D per cent is the highest available Daylight Factor in the part of the room which is critical from the lighting point of view (probably the part most remote from the window), then the level of supplementary lighting which must be installed is given by :

$$\left(E - \frac{D}{100}\,500\right) = (E - 5D) \text{ lm/ft}^2$$

For example, if the work requires 30 lm/ft² by the I.E.S. Code, and the highest daylight factor that can be achieved with the given layout of the room and possible fenestration is 2 per cent, the level of supplementary lighting would be given by :

$$30 - (5 \times 2) = 20 \text{ lm/ft}^2$$

The distribution of the supplementary lighting would, of course, on this basis, be designed to be a maximum where the daylight was a minimum, and to diminish in inverse proportion to the increase in daylight towards the windows.

This solution is good enough so far as it goes, but if it was the complete solution there would be no need for the skill in design shown in Fig. 2 and no need for this paper, because there is no new concept introduced unfamiliar to the lighting engineer.

(2) The Brightness Approach

The appearance of surfaces and objects in the room is governed partly by their brightness, and partly by the brightness of everything else in the room, in other words, by the adaptation level. If the adaptation level is high, things of a particular brightness will look darker than if it is low. In a room lit by daylight, the adaptation level can be very high if there is a view of bright sky. Consequently a surface receiving, say, an illumination of 10 lm/ft² of daylight may look very much darker than if it had been seen in an artificially lit room although receiving the same illumination. This is because the bright view of a large area of sky has pushed up the adaptation level to a value much higher than that determined solely by objects in the room, and thence depressed the subjective brightness of these objects[1] [2]. Even if the level of daylight illumination on the work in the darker parts of the room meets I.E.S. Code standards, seeing may be difficult because of unfavourable adaptation.

Therefore, a room which is inadequately lit by daylight poses two problems. First, there is the need to provide extra light to top up the inadequate daylight to enable work to be done efficiently —this we have already discussed—and second, there is the need to brighten up the gloomy parts of the room ; gloomy not necessarily because they

* The C.I.E. defined the Daylight Factor in 1955 as follows : The Daylight Factor is a measure of the daylight illumination on a given plane at a point indoors expressed as a ratio between the illumination on the given plane at that point and the simultaneous exterior illumination (excluding direct sunlight) on a horizontal plane from the whole of an unobstructed sky of assumed or known luminance distribution.

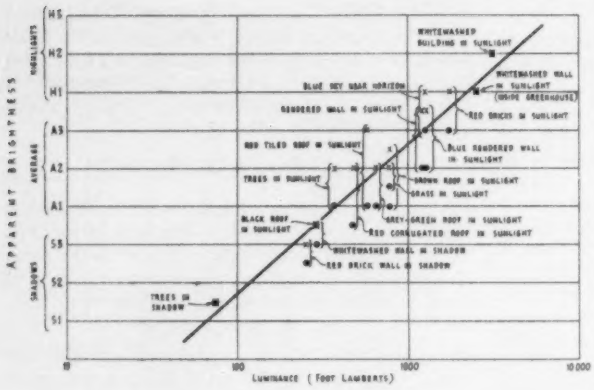

Fig. 3. Estimation by two observers of apparent brightness of objects out-of-doors in sunlight with clear blue sky. (Illumination at eyes, 630 lm/ft².)

receive little illumination, but because they are subjectively dark due to the high adaptation occasioned by the view of bright sky.

A close examination of the principle of supplementary lighting shows that this second problem is at least as important in practice as the first. To meet a lack of experimental data a study was therefore made to determine the balance of brightness between the daylighting and the supplementary lighting. This determination can be made, if we feel sufficiently confident in our fundamental knowledge, entirely on a theoretical basis. The steps are briefly as follows :

(1) Determine a representative value for the adaptation level of an observer in the room, e.g. by use of the B.R.S. Solid Angle Diagram(²). (See Appendix.)

(2) Determine the apparent brightness of critical areas in different parts of the room from data relating apparent brightness to adaptation level and luminance(¹) (²).

(3) Determine the necessary increase in apparent brightness in the darker parts of the room to balance those well lit by daylight.

(4) By reference again to the apparent brightness data, determine the necessary increase in luminance.

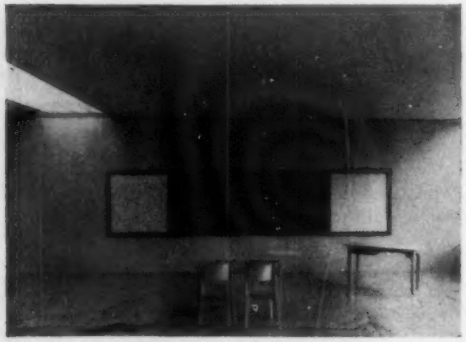

Fig. 4. Interior of model room used for pilot study of supplementary artificial lighting.

Such a calculation, though quite feasible, is tedious when a wide range of external and internal conditions has to be studied and success depends on the reliability of the basic data. While the published data on apparent brightness are probably sufficiently accurate for computations of this sort, our knowledge on what constitutes " gloominess," etc., is less adequate, and although studies by Longmore and Keyte made some years ago are of considerable assistance here (see Fig. 3) the information is incomplete for a basis of a new technology. The view was taken that the investigation would be better done directly, using well-detailed models in which judgments of brightness balance could be made. Initial calculations were made to obtain some idea of the probable levels of supplementary lighting necessary, to see whether or not the concept of permanent supplementary lighting was an economic possibility.

These calculations showed that, with a room having a window design giving a minimum daylight factor of the order of 1 per cent, the level of artificial lighting required to supplement the daylight and give an adequate balance of brightness between the different parts of the room would have to be of the order of 50 to 100 lm/ft². A rough estimate of savings in building costs showed that it was still worth going ahead with the study.

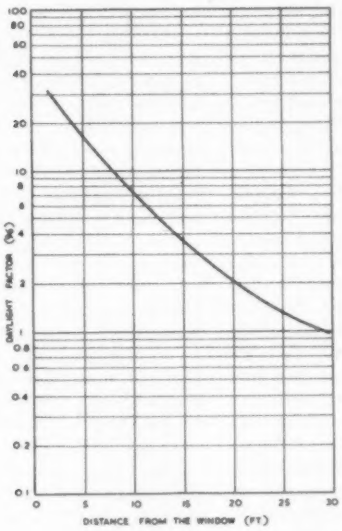

Fig. 5 (left). Distribution of daylight from side window in pilot study.

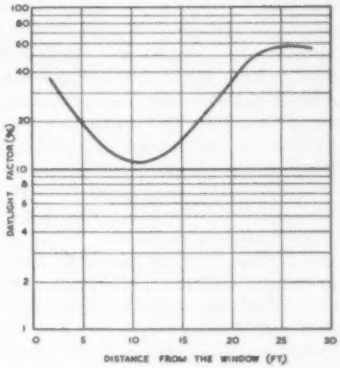

Fig. 6 (right). Distribution of daylight from side window and roof-light combined in pilot study.

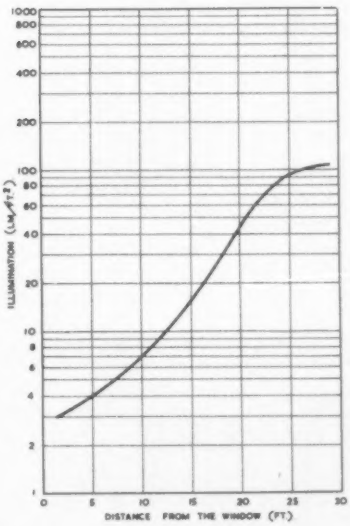

Fig. 7 (left). Distribution of supplementary artificial lighting. Mean level chosen by six observers in pilot study.

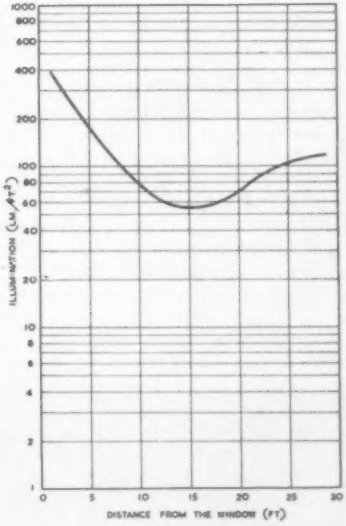

Fig. 8 (right). Distribution of daylight and artificial light combined for mean sky luminance of 1,000 ft-L.

(3) Experimental Work

(3.1) Pilot study

A pilot study was first made using a model of a room of traditional shape and dimensions suitable for an office or school classroom(4). The floor area was 30 ft. × 25 ft. (to a scale of 1 in. to 1 ft.) with a ceiling which could be raised, lowered or sloped as required. A large window on one 25-ft. wall of the room supplied the daylighting. The interior of the model was rather carefully detailed for colour and furniture to give a realistic impression to the observers. (Fig. 4.)

A laylight was placed at the end of the room remote from the window, which consisted of a white opaque eggcrate panel above which was

mounted a box containing two 2-ft. 40-watt fluorescent tubes, " Daylight " type, on a dimming circuit which enabled a sufficient variation of light output for the purpose of the experiment. A screened viewing aperture enabled the observer to put his eyes up to the model and adapt completely to the interior brightness conditions, as in a full-scale room.

Initially the ceiling was set at 10 ft. height. Six observers were recruited to assess the balance of brightness in the room. They were first shown the room lit only by the side window, and asked to study it in detail, noting especially how the back of the room was darker and more gloomy than the rest, and how sky glare caused some discomfort. They were then shown the room lit by the side window aided by daylight coming from the hole in the roof where eventually the artificial light was to go, and were asked to note how the additional light brightened up the room, and how the higher adaptation level reduced the discomfort from glare. They were then told that the purpose of the experiment was to see if artificial lighting in place of the roof-light could give as good a result, or better, when it was varied in amount. The box containing the tubes was then put into position, and the observer shown the effect of varying the amount of artificial light. After a short period to become familiar with the situation, the observer was asked to set the lighting level to give the best balance of brightness, acting on the following instructions : " Please set the variable lighting in such a way that the best balance of brightness between the different parts of the room is obtained. If you set too low, you will see that the back of the room will be gloomy, and if you set too high, you will find your eyes distressed by the double attraction of the bright window on the one side and the bright back walls on the other. You will also get an uneven brightness pattern on the side wall and perhaps some annoyance from the excessively bright ceiling. You may not be able to counteract entirely the sky glare, but try to strike the best compromise."

Observers made these settings with confidence, and the six observers did not differ greatly in their settings. Figs. 5 and 6 show respectively the distribution of daylight from the side window alone,

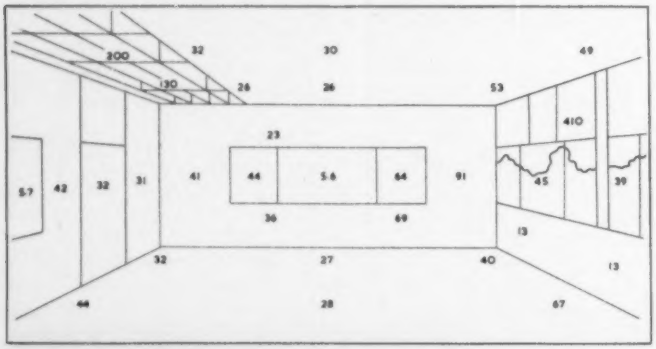

Fig. 9. Surface luminances (ft-L) in pilot study model, at mean of six observers' settings, for average sky luminance at 42 deg. of 1,000 ft-L.

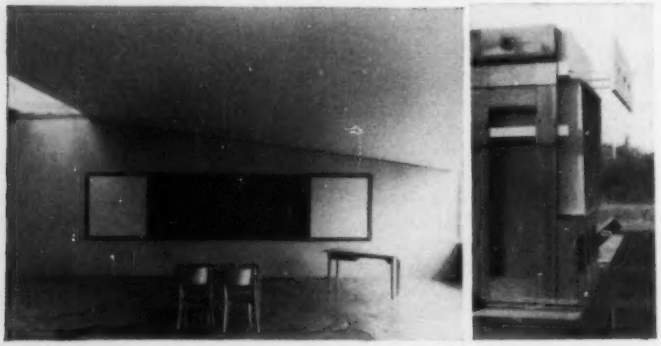

Fig. 10 (left). Ceiling sloped from 10 ft. at back of room to 7 ft. at window to reduce window area.

Fig. 11 (right). Vertical baffle or " outrigger " used to reduce subtended area of sky visible from inside model room.

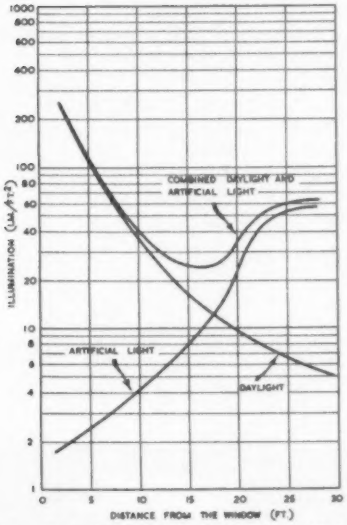

Fig. 12. Distribution of daylight, artificial light and total light with sloping ceiling. (Mean sky luminance 1,000 ft-L.)

and that from the side window and roof-light together. Fig. 7 shows the distribution of the supplementary artificial lighting when set at the mean level chosen by the six observers, and Fig. 8 shows the daylight combined with the artificial lighting. During the course of the experiment the average sky luminance was fairly steady at a level of about 1,000 ft. lamberts.

It was, of course, on the appearance of the room that judgments were made. Fig. 9 shows the luminance values which were measured at the mean of the six observers' settings.

The chosen levels were high, and of the same order as had been predicted from the calculations. This confirmed that the economics of the problem were to be thought of in terms of such high levels.

The solution arrived at in this first study left room for improvement. First, sky glare, although reduced a little by the raising of the interior brightness level, still caused some discomfort. Second, the distribution of brightness in the room, though better than with the side window alone, was not altogether satisfactory.

It was thought that improvements could be made by reducing the area of sky seen by the observer. Two solutions only were examined at this stage, and only one in detail. These are shown in Figs. 10 and 11. The first involved sloping the ceiling from 10 ft. at the laylight to 7 ft. at the main window. The other, studied later, involved the placing of a vertical baffle or " outrigger " outside the window.

Observers' judgments made with the sloping ceiling showed that the level of artificial lighting could now be reduced to about one half the previous value, with considerably less sky glare, and a more pleasing brightness balance throughout the room. Fig. 12 shows the distribution of daylight, artificial light and total light from this new solution.

This appeared to be the crux of the problem. Once the idea can be accepted of supplementary light to blend with the natural lighting in a room, as part of the basic design, we have the freedom to achieve a better all-round architectural and lighting solution than by daylight alone. When a room is entirely lit by daylight, the architect determines much of the character of the room by the way he designs and places the windows. If he has to achieve certain levels of daylight factor, he is constrained by the geometry. If, however, he can design the windows for appearance and proportion, and thence supplement the illumination from well-placed artificial sources, he has a new freedom of expression, and in achieving this he can pay more attention to ensuring good seeing conditions and absence of sky glare.

(3.2) Application of the basic principles

The pilot experiment established a basic principle on supplementary lighting, that is : Supplementary lighting must be of a sufficiently high level to establish a balance of adaptation between the brightly lit parts of the room near the window and the artificially lit parts of the room remote from the window. This high level is determined, not necessarily only by the visual task to be undertaken in those remoter parts, but by the subjective sensation of adequacy of brightness.

Arising out of this there is the corollary that, where possible, the daylighting and the supplementary lighting should be designed together to achieve a satisfactory blend. In many instances, this may mean smaller windows than would otherwise have been installed, and it may also mean the provision of built-in glare shields.

The establishment of this basic principle, either by theoretical or by experimental means, was not difficult, because it is clearly a matter of common sense and observation provided one thinks in terms of brightness—" what we see "—rather than of illumination. The next step was to apply the technique of supplementary lighting to specific cases, to see how it would work out, and in particular to see how much it would cost in comparison with other solutions.

Two opportunities arose at the right stage: one was the design of teaching laboratories for a technical college, and the other the design of a research laboratory. The fact that the first two projects were laboratories was fortuitous; the principles could have been applied to an office, a factory, a hospital or any other type of building.

In these two designs, the need to erect a model arose for a number of reasons, not all concerned with the design of the supplementary lighting. The studies were therefore conducted on models and the opportunity was taken to study additional variables connected with the design of the supplementary lighting, including:

(*a*) The effect of varying sky brightness on the level of supplementary light.
(*b*) The effect of changes in the reflection factors of the interior surfaces.
(*c*) The effect of position in the room of the supplementary lighting.

The method of experimentation was the same as before.

(3.3) The teaching laboratory

One teaching laboratory, selected for study as being representative of those in the proposed extensions to a technical college at Preston, is 36 ft. wide and 28 ft. deep with a 10 ft. ceiling. A preliminary determination of the available daylighting was made. An examination of the building site indicated that the obstructions caused by existing buildings beyond the site boundary were of the order of 5° to 10°.

Future industrial development on the surroundings to the site is likely to increase the present obstruction angle and reduce the daylight factor still further.

Daylight factors were calculated. The figures given in Table 1 show that with a 10-ft ceiling the minimum daylight factor in the laboratory 28 ft. deep is 1 per cent. For a minimum daylight factor of 2 per cent the room must be no more than 18 ft. deep. A recent investigation has, however, shown that a minimum daylight factor of 3 per cent is necessary in laboratories([5]).

If the ceiling height is increased to 14 ft. the minimum daylight factor is 1.8 per cent in a 28 ft. deep room and for a minimum daylight factor of 3 per cent the room must even then be no more than 20 ft. deep. Thus 3 per cent daylight factor is impractical for deep rooms with single-side lighting and some form of supplementary lighting would be required in all such rooms. In a multi-storey spine corridor block this cannot be provided by installing additional windows in the ceiling or side walls, and artificial lighting must be used.

Table 1

Daylight factors (minimum) calculated for 36 ft. wide laboratory

Room Depth ft.	Ceiling Height		
	10 ft.	12 ft.	14 ft.
	%	%	%
28	1.0	1.4	1.8
24	1.3	1.8	2.3
20	1.7	2.4	3.2
16	2.5	3.7	4.8

Fig. 13. General view of the model teaching laboratory and control gear for the artificial lighting.

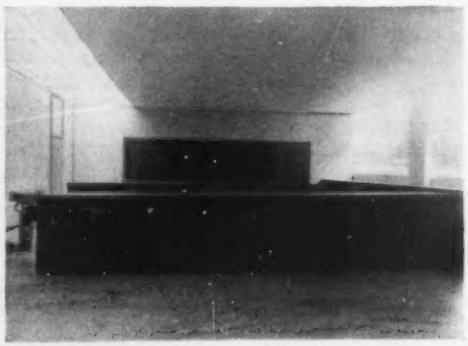

Fig. 14. Interior of the model teaching laboratory showing the laylight and louvred window design.

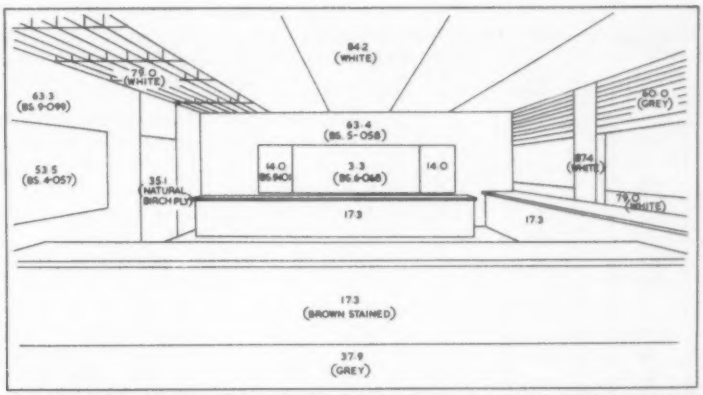

Fig. 15. Reflection factors (per cent) and colours of surfaces in model teaching laboratory.

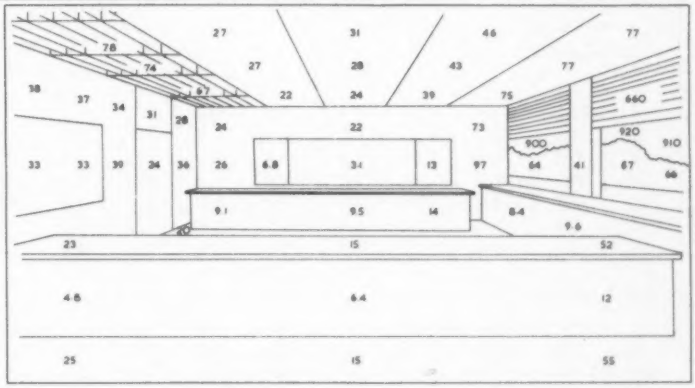

Fig. 16. Surface luminances in model teaching laboratory. Sky luminance at 5 deg., 1,000 ft-L; artificial illumination below laylight, 40 lm/ft²; total illumination at eye, 40 lm/ft².

Table 2

Illumination on 3 ft. working plane from laylight at back of room (expressed as percentages of maximum value on centre-line at back of room)

Distance from Window (ft.)	Centre-line (%)	2 ft. from Side Wall (%)
26	100	61.1
24	94.4	56.6
20	51.0	29.7
16	20.4	12.6
12	9.8	6.5
8	6.3	4.5
4	4.4	3.4

(3.3.1) *Model construction*

A model with demountable components was constructed to a scale of 1 in. to 1 ft. (see Fig. 13). The window wall could be easily removed to enable direct comparison to be made of a number of different window designs, each readily assembled on sheets of clear acrylic plastic. A system of supplementary artificial lighting was provided at the back of the room in the form of a diffusing acrylic plastic laylight 6 ft. wide extending the full width of the ceiling (see Fig. 14). Opaque white eggcrate louvers flush with the ceiling prevented a direct view of the laylight which was lit from above by two 3-ft. 30-watt " Daylight " type fluorescent tubes enclosed in a box and connected to a dimmer circuit. The dimming control on the tubes enabled a range of illumination from 0.1 to 130 lm/ft² to be provided at the back of the room. This was adequate for all conditions examined. A small inspection aperture in one

Table 3

Daylight factors measured in model laboratory 36 ft. × 28 ft. with various window arrangements

(No obstruction. Average reflection factor about 40 per cent)

Distance from Window (ft.)	Clear Glazing 3 ft. 0 in. Sill	3 ft. 9 in. Sill with Two 2-ft. Mullions Symmetrically Placed										
		Clear Glazing	Horizontal Louvers above 7 ft.	Translucent Laminated Glass above 7 ft.	Prismatic Glass ($<30°$) above 7 ft.	Prismatic Glass ($30°$-$40°$) above 7 ft.	Prismatic Glass ($>40°$) above 7 ft.	3 ft. Horizontal Baffle at 7 ft.	Translucent Laminated Glass above Baffle	Prismatic Glass ($<30°$) above Baffle	Prismatic Glass ($30°$-$40°$) above Baffle	Prismatic Glass ($>40°$) above Baffle
Centre-Line of Room												
	%	%	%	%	%	%	%	%	%	%	%	%
4	17.2	14.9	9.2	10.7	9.5	9.8	9.8	8.8	8.0	7.8	8.2	8.3
8	9.3	7.7	4.1	5.5	6.0	5.4	5.4	5.8	4.3	4.2	4.2	4.2
12	5.2	4.2	2.4	2.9	3.6	3.3	3.0	3.5	2.5	2.9	2.7	2.5
16	3.2	2.6	1.7	1.8	2.3	2.1	2.0	2.2	1.6	2.0	1.8	1.7
20	2.3	1.8	1.3	1.3	1.7	1.5	1.4	1.6	1.2	1.5	1.3	1.2
24	1.7	1.4	1.0	1.0	1.3	1.2	1.1	1.2	0.9	1.2	1.1	1.0
26	1.6	1.3	1.0	0.9	1.3	1.2	1.0	1.2	0.9	1.1	1.0	1.0
2 ft. from Side Wall												
4	13.8	12.3	7.9	9.0	8.1	8.3	8.2	7.5	6.7	6.9	7.0	6.8
8	7.0	6.2	3.2	4.1	4.5	4.2	4.1	4.4	3.1	3.3	3.3	3.2
12	3.8	3.3	2.0	2.1	2.7	2.5	2.2	2.7	1.7	2.2	2.0	1.9
16	2.4	2.1	1.3	1.3	1.8	1.6	1.4	1.8	1.2	1.5	1.4	1.3
20	1.8	1.5	1.0	0.9	1.3	1.2	1.1	1.2	0.9	1.2	1.0	0.9
24	1.4	1.2	0.8	0.8	1.1	1.0	0.8	1.0	0.7	1.0	0.9	0.8
26	1.4	1.2	0.8	0.8	1.1	1.0	0.8	1.0	0.7	1.0	0.9	0.8

The values of daylight factors in the table above are in no way to be interpreted as figures of merit for the various forms of fenestration. They apply solely to the special conditions, where no obstructions have been taken into consideration.

side wall enabled the interior of the model to be examined.

The interior surfaces of the model were decorated (by means of coloured paper to BS: 2660) and some model furniture and other detailing were provided to simulate a school laboratory. The average reflection factor of the room was about 40 per cent. The reflection factors and colours are given in Fig. 15.

A 25 mm. cosine-corrected selenium rectifier photocell calibrated for C.I.E. Standard Illuminant C (6,700°K) was used to measure illumination in a 3 ft. working plane. The photocell could be attached to a rod passing through the back wall of the model enabling it to be moved along the centre-line of the room and along a line 2 ft. from one side wall.

Measurements of surface luminances in the room from the combined daylighting and artificial lighting are given in Fig. 16 and correspond to a sky luminance at 5° elevation of 1,000 ft-L and a level of artificial illumination at 26 ft. from the window of 40 lm/ft².

(3.3.2) *Window design*

The design of the window was given some consideration in order to develop a system which would provide good seeing conditions in the room. Some form of screening was desirable to reduce the area of sky visible from inside the room to

limit the brightness of surfaces in the vicinity of the window and to provide a better distribution of light without necessarily having a maximum efficiency in terms of penetration to the back of the room.

Daylight factor measurements were made in the model with a number of different window arrangements to ascertain their effect quantitatively. The results which are given in Table 3 showed that on this basis there was very little difference in daylight factor between the various arrangements. Each tended to reduce the gradient of illumination on the working plane.

It was agreed that the final selection between the various window arrangements should therefore be made entirely on a subjective assessment of the visual conditions provided by the combined daylight and supplementary artificial light.

(3.3.3) *Appraisal of supplementary artificial lighting*

The experiments were conducted out of doors, because no sheltered space with full access to the sky was available. This was a grave disadvantage during the past summer, because it was almost impossible to collect the observing team together on a sufficiently fine day to permit the observations to continue uninterrupted by rain or by rapidly changing cloud formations. This fact alone accounts for the paucity of the experimental information.

The model was placed at one end of a field facing approximately west which enabled the effects of weak sunlight to be ignored. A row of trees at the far end of the field presented an obstruction of about 5° corresponding to the obstruction angle on the site of the proposed laboratory building.

A group of 10 observers was employed for the judgments. They consisted of members of the B.R.S. lighting staff and of the architectural staff of the Ministry of Education. All were experienced in appraising the appearance of an interior, in some cases possibly prejudiced, but it was felt better to employ skilled people on this type of judgment than " naive " observers.

Judgments were made on occasions when the sky was thinly overcast, with no direct sun visible, without rain and when cloud conditions were relatively stable and not altered by wind.

Each of the observers was asked to adjust the level of the artificial lighting exactly as in the pilot experiment described above.

Variable conditions unfortunately prevented any possibility of maintaining a constant luminance visible through the window while the measurements were being made. On the first occasion (Table 4) the mean sky luminance varied from 1,500 to 2,600 ft-L and on the second occasion from 1,000 to 1,600 ft-L (Table 5). A proportional adjustment was made to facilitate comparison of the settings of different observers, but it was not assumed that the level of artificial illumination required would necessarily vary in direct propor-

Table 4

Levels of artificial illumination (lumens per sq. ft.) at back of room required to supplement daylight on bright cloudy day

(*Sky luminance* 2,000 *ft. lamberts at* 5°)

Observer	Horizontal Louvers above 7 ft.	Translucent Laminated Glass above 7 ft.	Prismatic Glass above 7 ft.	Horizontal Baffle at 7 ft. Clear Glazing above
A	43.7	32.3	43.6 34.2	25.3
B	38.2	33.3	64.5 115.6	30.0
C	44.8	27.0	63.3 54.4	31.5
D	31.3	42.2	73.1 46.7	73.3
E	77.5	58.6	94.1	61.1
Median	43.7	33.3	63.3	31.5

Table 5

Levels of artificial illumination (lumens per sq. ft.) at back of room required to supplement daylight on bright cloudy day

(*Sky luminance* 1,000 *ft. lamberts at* 5°)

Observer	Translucent Laminated Glass above 7 ft.
F	38
G	27
H	40
J	19
Median	32

tion to the sky luminance, although this has since been shown to be the case.

(3.3.4) *Sunlight*

The effects of sunlight, both direct and reflected, on the balance of daylight and artificial light require further study. It may be preferable to exclude sunlight from the room completely by providing blinds which can be drawn on sunny days, but which may, however, allow a certain amount of daylight and diffused sunlight to enter the room.

The results of the present study indicated that, on overcast days, there was very little to choose between the different window arrangements examined in the model from the point of view of sky glare. A further examination under sunny conditions was made to ensure that direct sun on the window would not cause excessive brightness contrasts and discomfort from glare.

The orientation of the laboratory building will be more or less east-west. The windows of the room examined are to be on the west side and will face approximately 30° south of west so that they will receive direct, low angle, sunlight over the greater part of the afternoon, throughout almost the whole year.

The model was orientated correctly so that judgments could be made with direct sun on the windows. Designs incorporating prismatic glass became uncomfortably bright due to flashing by the sun of imperfections in the surfaces of the prisms.

Translucent laminated glass yielded a surface brightness of 3,200 ft-L when receiving direct sunlight and was similarly judged to be uncomfortably bright.

The most satisfactory solution in direct sunlight was considered to be one in which a system of thin white horizontal louvers was mounted inside the window from a height of 7 ft. to the ceiling. It was felt, however, that visual conditions might be still further improved if the louvers were inclined upwards to the ceiling at a small angle, say 20°, to obscure the view of sky completely but this has not yet been tried.

(3.3.5) *The effect of varying sky luminance on the level of supplementary light*

The method of experimentation was the same as before. The model teaching laboratory was fitted with the selected window design, i.e. clear glass with horizontal white louvers from 7 ft. to the ceiling. A team of 13 observers was employed for the judgments. They consisted of members of the B.R.S. lighting staff and also of the architectural staff, several of whom were unaccustomed to making lighting judgments.

In order to cover the greatest range of sky luminance in the shortest possible time a series of neutral tinted plastic sheets was employed to cover the window. These sheets had transmission factors, at the mean viewing angle from the observers' position, of 64 per cent, 34 per cent and 12 per cent. Thus four steps of sky luminance, covering a range of rather less than 10 : 1 could be obtained at any one time while eliminating the day-to-day variation in the assessments of the observer and minimising changes in sky luminance distribution. The overall range of sky luminance covered in the experiment was 57 to 2,210 ft-L, measured at an angle of 5° above the horizontal, that is, the sky visible to the observer through the window. (At this angle the luminance of the C.I.E. Standard Overcast Sky is one half the average luminance.)

Care was taken to ensure that the observers were suitably adapted to the brightness level in the model before they were asked to make a setting. A canopy of black cloth was erected over the viewing aperture, so that the observer could see nothing outside the model. A sliding door closed the viewing aperture while the window transmission was being changed so that the observer sat in darkness and was not aware that any change had taken place in the room. He was not told that the sky conditions had been altered and in fact several observers thought that they were being asked to repeat the same observation.

The judgments were made in decreasing order of sky luminance magnitude over a period of about 20 minutes.

The instructions to the observers were as follows: " This is an experiment to determine the levels of artificial lighting which would be required to supplement daylight in deep rooms lit by windows in one side wall. I want you to imagine that you are a student in a school laboratory and that you will be reading from the chalkboard and from books on the bench and using instruments on the bench. First of all I want you to look around the whole room and decide whether or not the back of the room is gloomy and requires some additional light. If you feel that it does I will give you control of the level of light provided by the laylight at the back of the room and I want you to adjust the level until you reach what you consider to be the most satisfactory balance of light in the room as a whole, i.e. when the artificial light dispels the gloom at the back of the room but is not so bright as to be glaring or the major source of light for the whole room."

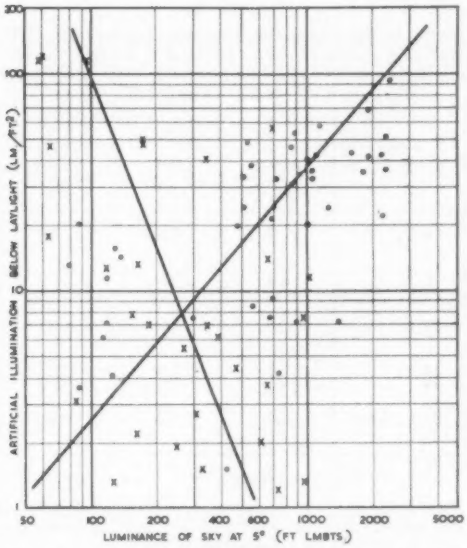

Fig. 17. Settings of artificial illumination in model teaching laboratory for varying sky luminance.

These instructions differed from those of the pilot experiment in that (*a*) the observer was left free to decide whether or not supplementary light was necessary, and (*b*) he was asked not only to judge the appearance of the room, but also to imagine that he was working in the room and reading from the chalkboard.

Throughout the experiment the illumination levels provided by the window and by the laylight were measured on a horizontal surface 3 ft. above the floor and 2 ft. from the back wall. The sky brightness was measured at 5° elevation in the direction of view of the observer using a visual telephotometer, corrections being made for the transmission factors of the neutral filters.

(3.3.6) *Results*

The results are shown in Fig. 17. At first inspection, the data presented a confusing pattern with little or no correlation. They were then examined in detail, and each observer's data were plotted out and the correlation determined for each between sky luminance and chosen level of supplementary lighting. An interesting factor then emerged ; a group of five observers gave a good positive correlation and the rest gave either a negative correlation or no correlation. Discussion revealed that observers had had some difficulty in interpreting the new instructions. Those in the first group of five had made their judgment entirely on the basis of the best balance between the brightness of the window and adjacent walls, and that of the back of the room. They had had some difficulty in making this judgment under conditions of low sky luminance, because even when a good balance was obtained, the whole room still looked gloomy.

One or two of the observers of the second group indicated that the instructions appeared to them to demand a difficult choice between two different settings of the supplementary lighting. When the sky luminance was low, the setting for the best subjective balance of brightness did not relieve the gloom in the whole room, but merely the gloom in the dark interior of the room. A much higher level of supplementary light was necessary to effect the best compromise with other factors, including ability to see well and to light up the whole room. The observers of the second group seem to have made their settings at this higher level when the sky was dull.

Again, with the high sky luminance, observers of the second group felt that the room was well enough lit by daylight, and so "opted out" of the requirement to provide supplementary light. They remarked, however, that if there was to be supplementary light and they were required to set the level, then the level must be very high. It appeared also that one or two of the observers of the first group were of the same opinion, but in their case they followed the instruction to set the level of the supplementary lighting that was provided, rather than opting out of the need to make a judgment.

The results on Fig. 17 have been divided into two groups, the open circles representing the data of those who showed a positive correlation between sky luminance and chosen level of supplementary lighting, and the crosses representing the data of those who did not. The full circles are judgments made earlier when the different window designs were being compared. The interpretation of the results will be discussed later.

Observers indicated also that the setting was never critical and that there was a range of level of supplementary lighting within which the appearance was acceptable. This range is of great practical interest, and it is intended to study it in later experiments. The present observations were based on what the observer felt to be the best compromise between a low level just sufficient to dispel gloom at the back of the room, and a higher level above which the room was excessively bright.

(3.4) The research laboratory

The research laboratory selected for study represents an extreme proportion necessary for functional requirements but which could not be lit by daylight from one side only. The dimensions are : depth 23 ft. 4 in., width 10 ft., ceiling height 9 ft. The window is 10 ft. wide and 5 ft. high from a 3 ft. 4 in. sill and the window head is 8 in. below the ceiling. This room shape was determined from a study of laboratory requirements by the Division for Architectural Studies of the Nuffield Foundation in their research on laboratory design([5]) ([6]). This particular room is a small laboratory designed to be used by one man and in single-storey buildings the daylighting would be supplemented by a roof-light at the back of the room. By using supplementary artificial lighting the laboratories could be built into a multi-storey building and one such room is to be included experimentally in the new Animal Research Unit at Cambridge of the Agricultural Research Council, for comparison with the other rooms which will be lit entirely by daylight.

(3.4.1) *Model construction*

A model of the laboratory to a scale of 2 in. to 1 ft. was constructed using prefabricated components of the B.R.S./Nuffield modular model technique([7]). The interior was detailed to give an impression of reality. A louvered laylight, 3 ft. 4 in. wide extending the full width of the ceiling, lit from above by two 2 ft. 40-watt " Colour Matching " (" Northlight ") type fluorescent tubes on a dimmer circuit, was used to provide the supplementary artificial lighting. The laylight projected below the level of the ceiling and spilled some light sideways on to the ceiling and the back wall.

In addition to the variables studied in the teaching laboratory model, the effect of position in the room of the supplementary lighting was investigated.

The laylight was moved forward in a series of 1-module steps (i.e. 3 ft. 4 in.) from the back of the room, i.e.

(*a*) with the back edge of the laylight against the back wall ;
(*b*) 3 ft. 4 in. and
(*c*) 6 ft. 8 in. away from it.

Three window arrangements were examined. These consisted of

(i) the clear glazed window uninterrupted by other than thin glazing bars ;
(ii) a white-painted thin vertical baffle or " outrigger," 2 ft. high, mounted 1 ft. 3 in. outside the same window at such a height that its centre-line was 6 in. below the ceiling ;
(iii) a white-painted thin horizontal baffle 2 ft. wide mounted immediately outside the same window at a height of 6 ft. 8 in. above the floor.

The purpose of these baffles was to reduce sky glare and improve the brightness balance in conjunction with the supplementary lighting.

Measurements of illumination were made in a 3 ft. horizontal working plane using a 25 mm. cosine-corrected selenium rectifier photocell cali-

Table 6

Daylight Factor measurements made on a 3-ft. working plane on the centre line of the model-scale A.R.C. research laboratory room for three window arrangements

Distance from Window Sill	No Baffle %	Vertical Baffle %	Horizontal Baffle %
4 ft.	9.1	6.6	7.7
9 ft.	3.4	2.6	3.3
14 ft.	2.0	1.3	1.4
19 ft.	1.2	0.8	1.0
22 ft. 4 in.	1.0	0.7	0.9

Table 7

Illumination from laylight on 3-ft. working plane on centre-line of model-scale A.R.C. research laboratory

(*Illumination expressed as percentages of maximum value occuring immediately below laylight*)

Distance from Window Wall	Laylight Adjacent to Back Wall %	Laylight 3 ft. 4 in. from Back Wall %	Laylight 6 ft. 8 in. from Back Wall %
4 ft.	5.2	7.7	11.7
9 ft.	9.3	15.3	27.9
14 ft.	19.5	45.5	92.5
19 ft.	71.8	97.7	50.0
22 ft. 4 in.	98.3	54.2	24.6

Table 8

Settings of supplementary artificial lighting for various combinations of window arrangement and laylight position

Window Arrangement	Mean Sky Luminance at 42° Elevation ft-L	Daylight Illumination at 22 ft. 4 in. lm/ft²	Laylight Position		
			Adjacent to back wall	3 ft. 4 in. from back wall	6 ft. 8 in. from back wall
			Artificial illumination below centre of laylight, lm/ft²		
No baffle	1,350	13.5	61.8	38.5	32.0
Vertical baffle ...	1,350	9.4	45.4	44.5	23.9
Horizontal baffle ...	2,510	22.6	82.3	61.0	60.8

brated for C.I.E. Standard Illuminant "C" (6,700°K).

Daylight factors measured on the centre-line of the room for the three window arrangements are given in Table 6.

The distribution of illumination from the laylight in each of three positions is given in Table 7.

(3.4.2) *Supplementary lighting judgments*

A small team of six observers was used to make the judgments. They were members of the staffs of the B.R.S. lighting section and of the architectural division of the Nuffield Foundation.

Judgments were made, under conditions similar to those of the previous experiments, of the supplementary lighting necessary with the three window arrangements and with the two laylight positions nearest the back of the room. Judgments on the third laylight position were discontinued after it was generally agreed this position did not provide a satisfactory distribution of brightness throughout the room, the back parts of the room appearing even darker by comparison with the bright areas in the region of the laylight.

(3.4.3) *Results*

The data were not sufficiently extensive to carry out more than as imple analysis. The mean sky luminance for each group of observations was determined. Then the individual settings of supplementary artificial lighting were adjusted to this level of sky luminance assuming a proportional relation over the limited range. The median of these values was then calculated.

These results are given in Table 8.

On the occasion when judgments were made for the horizontal baffle the sky luminance was higher than previously.

From these results it is seen that some reduction in the amount of supplementary artificial lighting can be effected, in a room of this shape, by moving the laylight towards the window. It was generally agreed however that, if the laylight was moved too far from the back wall, the quality of the lighting in the room was unacceptable and it was felt that the best compromise might be to increase the width of the laylight to say 1½ modules (5 ft.) and to place it at 1 ft. 8 in. or 3 ft. 4 in. from the back wall. This is to be tried in the model.

The big difference in sky luminance precludes a valid comparison between the effectiveness of the two types of baffle. However, it might be considered reasonable to deduce that, just as in the pilot experiment, the reduction in the daylight level enables lower values of supplementary lighting to be used.

Visual appraisal was slightly in favour of the vertical baffle, but clearly more detailed studies would be necessary.

(3.4.4) *Effect of daylight level*

Judgments were also made of the effect of changes in the level of exterior daylight, by the same method as was used for the teaching laboratory model. The small team who made these judgments were those who showed the positive correlation in the previous measurements. The data are shown in Figs. 18 and 19.

(3.5) Discussion of the results

The results so far available on the two studies described above suggest the following conclusions :

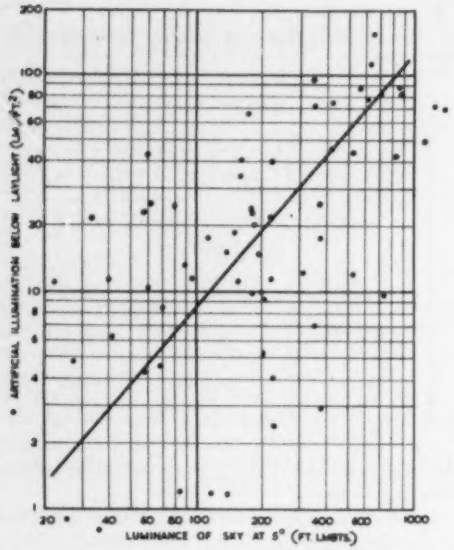

Fig. 18. Settings of artificial illumination in model research laboratory for varying sky luminance. (Laylight at back of room, no baffle on window.)

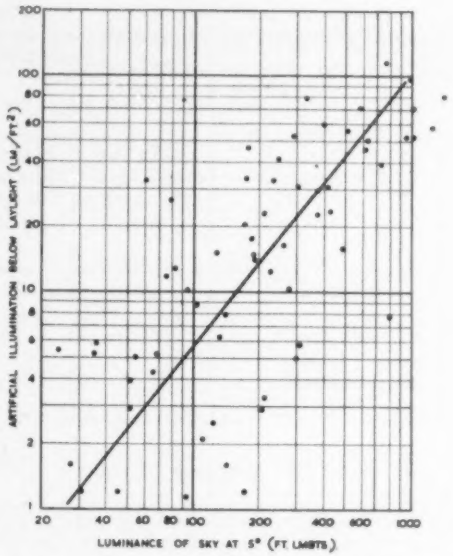

Fig. 19. Settings of artificial illumination in model research laboratory for varying sky luminance. (Laylight 3 ft. 4 in. from back of room, no baffle on window.)

(*a*) The relation between exterior daylight and interior supplementary light depends on at least three factors :—
  (i) necessary levels of light for working conditions ;
  (ii) acceptable balance of brightness between daylight and artificial light ;
  (iii) acceptable overall lighting, free from gloom or excessive shadows.

(*b*) The level of supplementary light necessary to give an acceptable *balance of brightness* between daylight and artificial light is shown experimentally to be proportional to the level of exterior daylight.

(*c*) The level of light necessary for an overall satisfactory solution may be high, and more or less independent of the sky luminance, because on dull days there is a need not only to balance the window brightness, but to enliven the appearance of the whole room.

(*d*) The level of supplementary light is dependent on the daylight factors at both the front and the back of the room, but that at the front, and in particular, the amount of unobstructed sky seen from the observing position, is the main determinant. The higher the adaptation of the eye at this point, the higher must be the level of supplementary light provided.

(*e*) The effect of the reflection factors of the room surfaces will be complex, and is still under study. The evidence is that high reflection factors near the windows, and low reflection factors remote from the windows, together may need a level of supplementary lighting higher than any other combination. The judgment of what is adequate depends on subjective impressions of lightness (reflection factor) and brightness, and not on illumination.

The effect of the sky luminance is the most difficult to take into account at the moment because of insufficient experimental evidence. It is necessary to fall back on experience and observation.

One of the valuable qualities of daylighting is that it varies and so is not monotonous. It seems unwise to sacrifice this quality by swamping the daylight with a high level of artificial lighting, to the extent that variations in the daylight go unnoticed. This would suggest that the level of

supplementary lighting should not vary, and that it should be based on a moderate level of sky luminance. The supplementary lighting will not then dominate the room.

Until more experience is gained, the decision has been made to base the level of supplementary lighting on that chosen to give a satisfactory balance of brightness at a level of average sky luminance of 1,500 ft-L. This level occurs very frequently throughout the working day at most times of the year([8]), and often corresponds to a degree of uncomfortable glare such that the need is felt for supplementary lighting to raise the interior brightness level.

If this value of sky luminance is accepted, the rest of the design can proceed, remembering that, in addition to the balance of brightness, the level of supplementary light must be sufficient to permit work to be done in the areas not fully lit by daylight, and that the level of supplementary lighting must be sufficient to go far to eliminate sky glare discomfort.

All these considerations lead to somewhere near the same order of levels. Inspection of the experimental data suggests that, for example, when the average sky luminance is of the order of 1,500 ft-L, i.e. 750 ft-L at 5°, the supplementary lighting should fall within the bracket of 20 to 40 lm/ft² measured at the reference point. This bracket would probably depend on the daylight factor and the configuration and decoration of the room, and may be narrowed when the daylight factor is reduced by virtue of screening devices introduced to ameliorate discomfort from sky glare.

It follows also that if the daylight and the supplementary lighting have been designed together, the supplementary lighting will have a lesser job to do in eliminating sky glare—the visible sky area will be less, and so the supplementary lighting, in raising the adapting brightness of the interior, will be more effective.

A minor, but not negligible factor is the effect of the supplementary lighting on dull days. The experimental studies showed that on dull days considerations of balance of brightness alone did not demand high levels of supplementary light. The evidence so far is that, if the level of supplementary light does not exceed about 50 lm/ft² the degree of out-of-balance is not serious provided the mean sky luminance exceeds 300 ft-L. Under such conditions the average brightness of the window portion of the room will not be less than one third that of the supplementary-lit portion. When the average sky luminance falls below 300 ft-L, the need will be felt to switch on the whole artificial lighting.

We therefore arrive at an approximate figure of 20 to 50 lm/ft² as a basic value for supplementary lighting. Clearly this value is subject to adjustment for any given conditions, and the sensitive designer will wish to work out the best compromise for his purposes from first principles. But if the level is much lower, the supplementary lighting will fail to give adequate brightness balance and freedom from glare on bright days. If the level is higher, it will swamp the daylight on all but the brightest days, and on dull days more recourse will be made to the general artificial lighting because the natural lighting will appear inadequate.

(4) The Costing of Supplementary Lighting

Once the basic lighting problems are settled, it is possible to assess the economics of supplementary lighting. This is a matter primarily for the architect, but the lighting engineer needs to be armed with the figures should he have to justify the cost of the lighting equipment on purely economic grounds.

The comparison must be between the cost of the whole building with supplementary lighting only in those rooms where it is needed, and the cost of the whole building as it would have to be were supplementary lighting not used. This is important, because it follows from current methods of building construction that if the ceilings of certain rooms have to be raised for functional reasons, the ceilings of other rooms not functionally concerned must nevertheless also be raised. Hence, the greater the proportion of such other rooms in the building, the greater will be the economic advantage of reducing all the ceiling heights and supplementing the lighting in those rooms where it is needed.

A detailed general statement of costing cannot be given here, although such studies are being undertaken at the moment at the Building Research Station. The Ministry of Education have, however, made an approximate costing for the specific case of the Preston Technical College which is the subject of one of the lighting experiments (see 3.3 above). These figures are tentative only and will be followed up by a study of the actual costs when the building is erected and is in operation.

Comparison is here made between the extra cost of installing and running supplementary lighting for six laboratories with a ceiling height throughout of 10 ft., and the extra cost which would be incurred if the rooms had been lit only by daylight—which would have resulted in the ceiling height throughout the building being 14 ft.

(*a*) *Extra cost of raising all ceilings from* 10-14 *ft.*

Extra cost of raising all ceilings on these floors to enable 2 per cent daylight factor* to be achieved in six laboratories :		
Capital cost	£13,500	
Amortized over 35 years at 5 per cent...	£825	per ann.
Total extra cost (excluding extra heating) of raising ceilings from 10-14 *ft.* ...	£825	per ann.

(*b*) *Extra cost of supplementary lighting in six laboratories, all rooms having* 10-*ft. ceilings*—

40 lm/ft² at back of each laboratory room provided by 12×80-watt "Daylight" type lamps mounted in strip laylight 6 ft. wide : the extra cost of such an installation above the cost of normal lighting for the six laboratories	£440	
Repaid over 15 years at 5 per cent	£43	per ann.
Extra current consumed during working day, 7,080 units at 2d. per unit	£59	,, ,,
Cleaning, re-lamping, maintenance	£27	,, ,,
Total extra cost of supplementary lighting	£129	,, ,,

On such a basis a clear saving is shown by the use of lower ceilings with supplementary lighting. The cost of heating the additional cubic space of the higher ceilings would also be considerable.

A building which comprised a greater proportion of room area dependent on daylight penetration would show smaller savings. It can be shown, however, that even if the building comprised only rooms which would either have to have supplementary lighting or be raised to 14 ft. ceiling height to achieve satisfactory daylighting, a saving of approximately 3d. per sq. ft. of superficial floor area would still result, assuming electrical current at 2d. per unit. A loss would occur only if electrical current exceeded 4½d. per unit.

* According to Table 1 above, a daylight factor (minimum) of more than 2 per cent cannot be obtained by single side lighting alone unless the ceiling is raised above the practical limit of 14 ft. The costing has been based on 14 ft. height, even though visual considerations in a laboratory demand 3 per cent daylight factor.

It cannot be too strongly emphasised that these figures are tentative and are based only on the factors relevant to this particular building, and they should not be quoted out of this context. A full statement of the effect of variants in costing is necessary to enable any other specific building costing problems to be solved.

An alternative building would be a thin, high tower block which would enable daylight to be provided in the rooms from opposite or adjacent sides. This would make the educational requirements of the building impossible to meet, and so no useful purpose would be met by considering the costing of such a design. However, in the case of an office building, for example, it would be a reasonable alternative to include in the comparison of costs.

(5) The Spectral Quality of Supplementary Lighting

The spectral quality of the lighting used to supplement daylight should be chosen so that the least irritation is caused to users by the obvious differences between colours seen under the one and the other. It does not necessarily follow that the supplementary lighting should have the nearest available match in spectral distribution. Daylight varies very much in quality, especially when sunshine blends with the light from a blue or a cloudy sky. The presence of supplementary lighting introduces a constant reference standard, not normally present, so that these variations in the quality of daylighting may be more noticeable. Only experience will tell if they are troublesome. Care in the selection and application of colour on the side walls will do much to reduce the differences seen in the daylight and the artificial illuminant.

Insufficient work has so far been done to enable any dogmatic statement to be made about the best light to blend with daylight. Personal choice, made with some care and with reference to experience, led to the use of "Daylight" fluorescent lamps for most of the experiments described in this paper. The blend is not perfect, but it was not considered objectionable by any of the observers, some of whom were architects with extensive experience in the prescription of colour in buildings. "Colour-matching" ("Northlight") type lamps were also used.

It may be that, should the principle of permanent supplementary lighting be adopted widely, lamp manufacturers will devote some attention to producing a type of fluorescent lamp best suited to the purpose.

(6) Lighting After Dark

The problem discussed in this paper is the problem of good lighting in the daytime. It is necessary to decide to what extent the supplementary lighting can be used as part of the general lighting after darkness has fallen.

It has been suggested, particularly by Danish lighting workers[9] that there should be a complete change of character of the lighting after darkness has fallen. This may involve a change in the levels or in the spectral quality of the light or of the brightness distribution in the surroundings and the amount of sparkle produced by the sources. There is a great deal to be said for this. If the principle is accepted, the supplementary lighting would be something entirely separate from the night-time lighting, and would be switched off just as soon as the daylight outside fell to a level incompatible with efficient working indoors. The normal night lighting would then be switched on.

Economic considerations may make this principle impractical at the present time, so it is necessary to study how the supplementary lighting can be integrated into the general night-time lighting. With present-day lighting practice, levels of 30 to 50 lm/ft^2 are common (these levels have already been exceeded in normal lighting practice in the United States), so that there is little likelihood of the levels desirable for the permanent supplementary lighting being found excessive in comparison with the general lighting in the room.

The main problem will be in the distribution of light. A distribution which is designed to supplement that given by a large side window, for example, may not match satisfactorily any other distribution. If, however, the supplementary lighting comes from a laylight, as in the experiments described in this paper, it can be integrated with a luminous ceiling for use at night. This is the easiest of solutions.

A simple switching arrangement could enable some of the tubes in the supplementary installation to be switched off when the general lighting is switched on. Such a system is to be employed in the Technical College. Better still, the complete installation, daylight, supplementary lighting, and night-time lighting will be conceived as a whole, as in the example given in Fig. 2, producing a solution which is satisfactory to the architect, the engineer, and the user.

(7) Conclusion

The principle of permanent supplementary artificial lighting has been put forward as the best way of solving an urgent problem in the lighting of buildings. The need to make the fullest use of site space, and to build as economically as possible, leads to the use of deep rooms without recourse to high ceilings. Such rooms cannot be well lit to adequate standards of lighting by daylight alone. Nevertheless it is felt that daylight in all its variety and stimulation must be provided, and must be the dominant feature of the room lighting, rather than that it should be shut out by blinds or merely allowed to peep through small view windows. The only way to achieve this end in these circumstances is by the use of permanent supplementary artificial lighting.

Acknowledgments

This paper records part of a programme of lighting research undertaken at the Building Research Station of the D.S.I.R. in co-operation with the Ministry of Education and the Division for Architectural Studies of the Nuffield Foundation. The work is part of the programme of the Building Research Board, and acknowledgments are made to the Director of Building Research for permission to publish this paper. The authors wish to thank their colleagues of all three organisations for their help in the experimental work.

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Appendix 1

The Assessment of Glare from large sources such as the Window and the Supplementary Lighting

Glare from a very large source can be assessed according to the formula :

$$G = \frac{1}{Bb}\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} Bs^{1.6}\omega^{0.8} f(\theta.\phi)\, d\theta.d\phi \quad \ldots\ldots\ldots\ldots\ldots(1)$$

that is, by the sum of the glare effects of small elements of the large source, corrected for the position of these elements in the field of view.

G is the Glare Constant, whose magnitude depends on the degree of glare discomfort (G=35 for " just acceptable " glare).

B_b and B_s are respectively the luminances in foot-lamberts of the general surroundings and the source.

ω is the apparent size, in steradians, of the source.

$f(\theta.\phi)$ is the expression of the allowance to be made for the position of the source in the horizontal (θ) and the vertical (ϕ) directions. This expression is complex and is usually given graphically in the form of Position Index diagrams. The integral of the ω and the Position Index components can best be obtained by the method described by Petherbridge and Longmore(8).

The glare likely to be experienced (on average) from the installation of the experiment of section 3.3 above can thence be computed as follows :

The installation as seen from the observing point is first plotted on a semi-sinusoidal plotting web as shown in Fig. 20. The mean luminance of the scene can then be determined, as described by Petherbridge and Longmore, and this gives the B_b term in the Glare Formula. The solid angle subtended by the glare sources (here the window and the laylight) can also be obtained directly, without correction for Position Index.

The layout of the glare sources can now be plotted on the B.R.S. Position Index diagram, as described (3) giving the integral of the ω and Position Index terms.

Two glare determinations may now be made. First, a substitution can be made in the simple formula :

$$G = \frac{B_s^{1.6}.\omega^{0.8}}{B_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

taking the values of B_b and ω as those computed

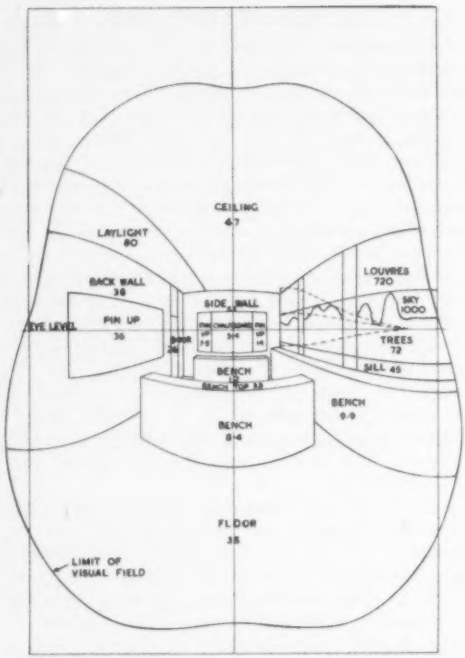

Fig. 20. Assessment of glare in the teaching laboratory of Section 3.3. The interior of the proposed laboratory (see Fig. 14) plotted on a semi-sinusoidal projection, together with average luminance (ft-L) of end surface. The broken lines show the reduction in the effective solid angle subtended by the window when allowance for position index is made by means of the B.R.S. position index diagram.

directly from the semi-sinusoidal diagram. This gives the degree of glare without correction for Position Index. The argument in favour of this is that in an interior the eye wanders freely about, without any fixed direction of view, and that therefore no modification for the position of the sources in the field of view is necessary.

If, however, such a modification is desired (on the basis, for example, that the main direction of view in a teaching laboratory is in the direction of the chalkboard), the values of B_s and B_b are the same as before, but the value of ω is that obtained from the B.R.S. Position Index diagram. The substitution is made in formula (2) as before.

Values of G have been computed on both bases for the installation of section 3.3 These are as follows :

Greatest degree of glare likely to be experienced by 85 per cent of normal observers under the

conditions of mean window luminance of 790 ft-L:

(*a*) no correction for Position Index:
$G = 309$;

(*b*) with correction for Position Index:
$G = 84$.

Since $G = 35$ for "just acceptable glare," 150 for "just uncomfortable glare," and 600 for "just intolerable glare," the installation will give some glare discomfort, but this will be better than the standard accepted for the I.E.S. Code (just uncomfortable) for most observers when looking in the direction of the chalkboard. This glare is due entirely to the bright sky, the supplementary laylight having a glare factor of only 2.

The above method is based on techniques published so far. Work is at the moment being undertaken to study more precisely the problem of glare from sources so large that they influence the adaptation level profoundly such that the independence of B_s and B_b in the Glare Formula can no longer be assumed. A preliminary report on this study has been made (10). This work indicates that in circumstances such as those of the installation of section 3.3 the visible surface luminance of the supplementary lighting must be kept below 200 ft-L (this has in fact been done in the present design). Careful design of the supplementary source is necessary to direct light on to the work and the walls, and as far as possible away from the observer's eyes. Good techniques for this exist and need not be discussed here. It will be appreciated that a good design will take into account the fact that the desired surround brightnesses can only be obtained by a combination of direct light from the sources, and reflected and interreflected light from the floor, the working plane and the walls.

Appendix 2

Determination of the Range of Acceptable Balance of Daylight and Supplementary Light

The range of level of supplementary light required to provide an acceptable balance with daylight, and hence the range of sky luminance for which a constant level of supplementary light is acceptable, was determined experimentally.

Seven observers were employed to make judgments in the teaching laboratory model and the experiment was conducted in two stages. Each observer was first asked to make three settings of the level of supplementary light, the first setting to be that level which just makes a useful contribution to a balance of brightness with the daylight; the second setting to be an optimum, i.e. the most satisfactory balance obtainable with the given arrangement; and the third setting to be the highest level acceptable, above which the supplementary lighting begins to swamp the daylight and dominate the character of the room. These settings were repeated for four sky luminances covering a range of rather less than 10 to 1. The instructions were recorded and played back to each observer to ensure that each received exactly the same instructions.

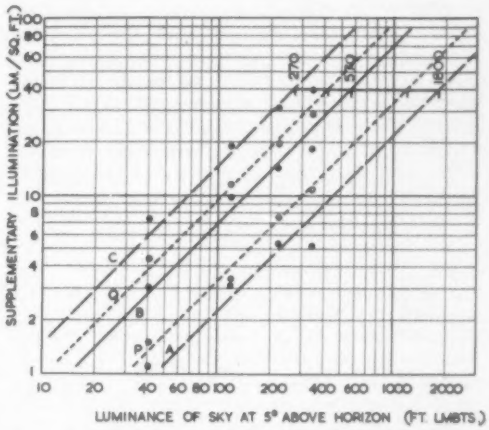

Fig. 21. Permissible range of sky luminance and supplementary light for acceptable brightness balance in a side-lit room of 1 per cent minimum daylight factor and supplementary top light at back of room.

In the second stage of the experiment the observers were asked to vary the supplementary light up and down and to give a series of six settings for each of the upper and lower limits alternately of the satisfactory range. The settings were again repeated for four sky luminances.

The results are shown in Fig. 21. Each observer's settings were averaged arithmetically and the medians of these averages are plotted against the luminance of the sky seen through the window. The medians lie approximately on parallel straight lines, A, B and C are respectively the minimum, optimum and maximum settings in the first experiment and P and Q are the lower and upper limits of the balance obtained in the second experiment. Any given level of supplementary light is therefore satisfactory for a range of sky luminance of about 6 to 1, or from one half to three times the design level.

These data provide a basis for deducing the permissible range of supplementary lighting. The design level should not be high so that the

supplementary lighting will never dominate the room. It will therefore correspond on the diagram to quite a moderate level of sky luminance. This basic level should, if possible, serve both dull winter skies and summer sky luminances which can reach 4,000ft lamberts average. McDermott has shown, in Illumination Research Committee Technical Paper No. 19([11]) that the ordinary artificial lights in a room are switched on when the outdoor sky illumination falls to a value given by $E=\frac{500}{D}$ where D is the daylight factor (per cent). For example in a room such as the Preston classroom with about 1 per cent minimum daylight factor this critical level of daylight would be about 500 lumens per sq. ft. from the sky. Hence the supplementary lighting would not be called upon when the sky illumination fell below this level.

The limits for the sky luminance *as seen through the windows of this room* can therefore be deduced (as explained earlier in the paper) as between 250 and 2000 ft. lamberts. From Fig. 21 it is seen that an installation designed for a sky of 570 ft. lamberts as seen through the windows (abscissa scale) and therefore demanding an optimum level of supplementary light of 40 lumens per sq. ft. will cover the sky luminance range from 270 to 1,800 ft. lamberts.

The design of supplementary lighting for rooms having minimum daylight factors other than 1 per cent may be based on a proportional relation between the level of supplementary light and the daylight factor as found in the pilot experiment. Further work is necessary to establish the exact relation and to determine the influence of the area of visible sky and of adaptation effects.

Discussion

Prof. MOGENS VOLTELEN : It is a great honour to me to have the opportunity to address this audience tonight—and as Vice-President of your younger sister organisation the Danish Lighting Society I have a special pleasure in conveying the greetings of my association to this dignified and venerable Society and our congratulations on your attaining your fiftieth birthday in such evident good health.

I am specially pleased to be given the opportunity to comment on the present paper, because I, as an architect, appreciate the attitude of the scientists who prepared this paper. It is an attempt to unite the physical and the psycho-physiological criteria within the science of lighting. This is a rather new phase in the development of our science. Both the physical side and the psychological side have been taken care of for a rather long time, but by different persons, in different directions, and speaking (in a way) different languages. In this case we find scientific methods applied to partly psychological facts—methods that are based on previous works from the same sources. I do think this is a major road into the future—even if we have seen only one or two miles of it so far. I will make an attempt to look a little further along this road and maybe have a glimpse of what is round the next corner.

In doing so I am going to try to introduce an architectural point of view to the problems of lighting. To introduce architecture and art to the science of lighting is not so silly as it may sound—as it is simply an attempt to make lighting serve man better. When we remember that lighting has no other purpose, this is clearly an appropriate endeavour.

I am not going to deal with the obvious demand that the lighting should be sufficient for the work to be done. I am going to concentrate on what the authors call " the balance of brightness." In part of the investigations there seems to have been a little confusion about what is understood under this concept. I think I can widen this confusion a bit more—and through this possibly contribute to a clarifying.

In surveying a room you may judge the " balance " in the room simply as a quality of the brightness pattern in the room. This is what is mainly done in this case. But considering the room as a real room to live in and to work in you will actually judge the balance in another way too. You will have (probably unconsciously) an architectural apprehension of the room. This is mainly a side-lit room and this is your dominant impression of it. In a side-lit room it is expected that the light is stronger near the window than closer to the back-wall. This fact is supporting the clear impression of the room, the impression that makes you feel at ease in the room. It may cause some confusion—you may say lack of balance —if the opposite proportion of light is seen. The architectural balance of the room is dependent on the light also—and this balance is not necessarily identical with the other sort of balance. This problem is more grave when the brightness of the sky changes so that at one time the window part of the room is the brightest (which is the natural condition) but at another time the back part of the room is the brightest. During the day the room will seem to tilt and this is not an agreeable experience.

It may be that we here are at one of the points where model studies fail. In fact you are—in

some of the experiments—surveying a room by peeping into it, not by living in it. Your experiences are in these cases not complete, not precisely the same as the real ones would be. In this connection I would like to introduce still another point which may be an important addition to the views of the paper. Through experience I have learned that the modelling of the forms and thus the precise apprehension of things in the room is very much dependent on a certain unity in the direction of the light. If you have light coming from two distinctly different directions and these two components are fairly equal in strength you will have a confusing pattern of shadows and thus a doubtful conception of shape. This is also an architectural problem. I think that in the cases described you may find it advantageous to place the toplight far nearer to the window and by oblique louvers direct the light towards the back wall and thus have two sources of light with substantially the same direction of light.

As to the problems of balance the authors have dealt very briefly with the problems of colour balance, stating correctly that the daylight varies considerably in colour temperature. May I mention briefly an attempt to solve this problem by an invention made by a Danish colleague and myself a couple of years ago. We took out a patent in 1949 on a device where we had an artificial roof light similar to that dealt with today and with an automatic regulation of the artificial light both in level and colour temperature according to the changes in daylight. In fact we aimed at a variation exactly proportional to that of the natural daylight both in colour and in level by using a combination of fluorescent tubes of very high and very low colour temperature so that the light from both were mixed in varying proportions before reaching the room. We were confronted with older patents using automatic regulation of the level of supplementary light, but all of these were working from the opposite principle ; when daylight decreased, the supplementary light should increase and vice versa. It is interesting to see that this same object has been in the mind of some of the observers in the experiments described. Both may be justified. One has a view to efficiency of work whilst the other has a view to what I may call architecture and comfort.

As a partaker in a discussion I imagine I have the privilege of widening the scope of the investigations far beyond the limits which the investigators themselves had to set. Being a notorious heretic I would then question the necessity of lighting the room as a whole through this additional lighting. Why not introduce local lighting at the very places where high levels are necessary for the work to be performed ? This light will have far better modelling properties and it is cheaper to attain the necessary level of illumination. In addition I think that this lighting installation would be better suited for combination with the pure artificial light during night. I know there is much to be said both against and in favour of this solution but at this moment I will confine myself to a mere mention of the possibility.

I hope that the authors and the Building Research Station will continue their valuable investigations on these subjects.

Mr. D. J. HARRIS : I welcome this paper for two particular reasons ; firstly, because it deals with a subject that all lighting engineers come across, and I suppose all architects, and secondly because the paper gives a very definite sort of conclusion. Dr. Hopkinson was not quite so definite when he spoke, but I still think the great advantage of this definite conclusion is that we can all go and try it out. There are plenty of buildings up and down the country where it seems to me that the authors' ideas could be applied and would make existing accommodation more useful to those who occupy it. There is a tendency in purely daylit buildings for the occupants to crowd towards the windows. Now I know the authors say in the paper that supplementary artificial lighting should not be put in to save a bad building, saying to the architect do not design a building with bad daylight so that the engineer has to put it right. Surely there is nothing to stop a lighting engineer taking an existing building and trying to improve the daytime lighting.

There are one or two points that I wanted to ask the authors, and although Prof. Voltelen has touched on these, I still think I had better ask them because I and others have not seen these models and I hope that the authors' answers will help us. With the model, you peep through an observation hole. Are the authors confident that, as you look through this hole, you really do get the same impression as you would have if you sat in the actual room ? If you look straight ahead you have a normal field of vision, but if you look to one side your field of vision is reduced. Also you have only one point of view. It seemed to me too, from the models that the authors showed, that you could not really see, by turning to one side, the whole of the window or the whole of the back wall of the room.

On the question of daylight factors, I notice that the authors mention that these are used in

the north west of Europe, and I take it they say that because they are not used in Great Britain, except of course by the Ministry of Education who seem to be particularly interested in daylight factors. But undoubtedly new buildings in this country, the common or garden buildings, have very low ceilings, and I believe that a large number of modern buildings do not meet the approved daylight standard for the class of occupation in some rooms, so that even modern existing buildings would benefit from some supplementary artificial lighting.

Another point about this question of observation through a hole in the side of a model room ; if one was in the actual room, particularly these laboratories that the authors are dealing with, one would get up close to some object and the point of view would matter very much when the local object occupied a large part of the whole field of vision. That is a thing I do not think you can see from a model.

The authors have chosen a number of rooms to experiment with, for very special reasons, but the rooms that they have chosen have been rooms where the daylight factors are not as they should be. I wonder if they could do similar experiments in rooms where the daylight factors are as they should be. This would answer the question : to what extent are the authors improving on what can be done with daylight and to what extent could they achieve good lighting by changing the window dimension or height of the ceiling ? Dr. Hopkinson did touch on this subject, but I do not think it would be possible from the figures he showed to divide the benefits into these two parts.

Mr. W. ALLEN : I would like to say this first of all—I think most of us have come to associate a major paper by the Hopkinson outfit as being associated with good demonstration, and I would like to congratulate Dr. Hopkinson on this remarkable display of adjustable brightness in projected pictures of lighting.

Turning to serious matters, it seems to me that they are underplaying the importance of this. We all know that something like this has been done in the past, seldom deliberately, occasionally successfully but rather roughly. As Dr. Hopkinson knows, the Americans have been feeling for some time towards this sort of thing, and I think we have occasionally laughed at them for some of their apparently paradoxical ideas ; for example, for making large windows and then introducing blinds and tinted glass all to cut down the brightness, and then building up the artificial lighting inside and using it all day. On the face of it, it does seem paradoxical ; but it is not, and the idea is economically exceedingly important.

I remember that in 1949 or thereabouts, one or two schemes of 50 ft. office depth were built. More recent and more significant is the Mile High Centre in Texas, because for the first time it offered a plan of a building with a variable depth of space in a big rectangle. The core of lifts and services was off-centre to the extent of providing in some spaces 25 ft., and in others 75 ft., depending on artificial light combined with the daylight. I think that was a most significant plan, for it does point very clearly to the economic importance of this sort of thing. We work to very shallow depths in our building in this country, about 18ft. from the window wall to the corridor. The Americans always work to 25 ft. depth, but if these depths go up to 40, 50 or 75 ft., the economics of certain types of building are fundamentally altered.

This is one of the key points. If you are dealing with industrial building it is a different sort of problem economically, but it still is an economic point you are dealing with.

I do so much agree with Professor Voltelen in his suggestion that the day and the night should be separately considered. Sometimes in a factory it will not be very different, but I think for other kinds of rooms it will be very important.

Mr. P. A. STONE : Dr. Hopkinson has shown us tonight how we can use P.S.A.L. (Permanent Supplementary Artificial Lighting) to remove the restriction imposed on designs by the need for adequate lighting. His figures for the Preston Technical College indicate that in that case, where the planning requirements were so rigid, the only alternative was P.S.A.L. in six rooms, or raising ceilings everywhere ; P.S.A.L. provided the cheaper alternative. But this is a rather special case, and it is interesting to speculate on how far P.S.A.L. provides an economic solution in other cases.

For P.S.A.L., or any other design solution, to be economic, it must, of course, offer better value for money than the possible alternatives. In order to assess this, it is necessary to compare the difference in total user costs between the alternatives, against the differences in appearance and utility. We must, for example, estimate the difference between the extra costs of lighting by P.S.A.L. and the extra costs of construction, maintenance, cleaning and heating when ceilings are raised. The estimated difference can then be compared against our subjective valuation of differences in room heights, building heights and lighting standards.

Where room depth is of no importance it would appear to be generally cheaper in terms of total costs per square foot to use shallow rooms with natural lighting rather than deep rooms with P.S.A.L. But even here cases may arise where the reverse is true ; for example, where city plots are rather deep.

Clearly P.S.A.L. is most likely to provide the cheaper solution where one of the planning restrictions is room depths greater than can be lit adequately with normal ceiling heights. For single-storey buildings and top floors, clerestory windows or roof lights will usually provide the cheapest solution. For ground floors of two-storey buildings, raising ceiling heights will normally be a cheaper solution than P.S.A.L., but raising ceilings is hardly practicable when room depths get very great, as in industrial premises.

The costs of construction tend to rise with the height of the building, while the costs of P.S.A.L. remain constant and so the probability of P.S.A.L. being the cheaper will increase. For some three-storey buildings P.S.A.L. may be cheaper than raising ceiling heights. The balance of advantage for the P.S.A.L. solution will increase the more monumental the building, the shorter its expected life, and the cheaper the price of electricity, and in accordance with the standard of P.S.A.L. adopted. Since the cost advantage of P.S.A.L. tends to be marginal, it is necessary to look at each case individually.

Of course, in the special case where all but a few rooms are adequately lit by natural lighting, P.S.A.L. will often provide a cheaper solution than raising ceiling heights. But there may, in some cases, be planning alternatives which are more economic, for instance, grouping the special rooms at the lightest end of the building, or raising the ceiling height of these rooms only and perhaps even making them of double storey height.

Mr. Derek Phillips : I should like to associate myself with the views of Professor Voltelen regarding the question of light distribution from a combination of daylight with artificial lighting. This will need to be very carefully designed to avoid a conflict of distribution which may destroy the clarity of form normally associated with natural lighting. The idea mentioned, whereby supplementary artificial light is used only for functional reasons in specific areas, seems to have much to recommend it ; it will produce a contrast of light and shade which though not the same as the daylight distribution will be similar in quality to the natural daylight pattern.

I should like to ask two questions ; firstly, how do the authors assess the effect of the brightness of the louvres in the subjective evaluation of their observers ? For example, had the illumination level and wall brightness been derived from a method of lighting using black louvres would the results have been the same ?

Secondly, what has been the experience in factories which are lit entirely by artificial means at the change over from day to night ? Has it been found that a lower level of illumination is acceptable after dark when the view through vision strip windows clearly indicates nightfall ?

Mr. Allen mentioned buildings in America in which spaces are planned to depths of as great as 80 ft. Surely there must be a stage at which " Permanent Supplementary Artificial Lighting " becomes " Artificial Lighting " with " Supplementary Day-lighting " in which case the problem must be chiefly one of control of sky glare.

Finally, I would like to record the successful use of the B.R.S. model making technique which has evidently been used throughout these studies to achieve effective results with economical means.

Mr. R. R. Holmes : I was particularly pleased that Dr. Hopkinson has landed the responsibility for the artificial lighting right in the building constructor's lap. His reference to the brightness pattern is an approach I think is vital, and in particular I wonder whether some of the wide range of observations he obtained may have been due to the fact that in a classroom with a blackboard, the blackboard occupies the centre of the visual field, and that very often the system inincludes supplementary lighting on this blackboard. If you have a window down one side and no blackboard lighting you get one general direction of lighting ; and if you introduce artificial lighting opposite to that, you tend to get confusion. I think we should try to produce a brightness pattern with a centre of interest, as this is likely to lead people to give more consistent results through not being confused by a slightly unusual pattern of brightness.

With regard to the figures in Table 4, I would like to know what the significance is of the two figures in brackets.

Mr. Brian Anstey : Naturally I would like to join in the congratulations to the authors of this paper, and especially because I know something of the work that they do put in, and I have done work with models myself. Nevertheless, I think that they are on dangerous ground if they are misled into thinking we have now got somewhere

from which you can usefully do a bit of designing. I think this method of experiment is full of error. For one thing, it is so terribly over-simplified. I know you have to simplify, but it is so simplified as to distort the whole picture. I would like to say, for example, that when you are standing looking at something the mere shadowing of the eyebrows has an effect which is totally absent when you view this model from a fixed sight place. I should like to say the levels of illumination discussed appal me. I heard something of the order of 100 lm/ft² and 40 to 50 lm/ft² as desirable. I regard this as quite wrong. Now this room, for example, has lighting of the order of, say, 2,000 watts and the area of the room is 2,000 sq. ft., that works out at 1 watt per sq. ft.; I make a judgment of the illumination level as about 5 or 6 or perhaps 7 lm/ft². It seems to me too little attention is given to the variation in sorts of daylight. It is all very well to set up a model or building in a field and think in terms of uniformity. You take a standard horizon in open conditions of 15 degrees and you know very often it will be more. Much more certainly it will vary all over the field of the angles subtended by the horizon to your room. The result is that your contours inside the room will be nothing like even, and you cannot even ensure that they will remain as they are.

This is a very serious problem, and it should be regarded as such, and not in the light-hearted manner in which I am dealing with it. Again look at the position of the blackboard. If the room is full of children looking at the blackboard all the light appears to be on that side or the other side, and yet every one of the observers has a different quantity of light reaching him from that central feature, and what is more, the conditions of brightness will vary, and to attempt to think you can solve this problem with a model and one field of view is quite wrong.

We have heard about ceilings and the cost of high ceilings, and I do think it needs to be noticed that the artificial lamps must be put in somewhere and you need 2 ft. more height for most types of ceiling to provide the illumination. Do we want these low ceilings, and do we want to become like battery hens reduced to a cage, in which you can just stand or sit with ceilings crammed down on our heads, so that we can just work at our maximum efficiency until we pour out to our homes?

Mr. A. G. Smith: The wide scatter of results given by the observers in the experiment on the model laboratory must have been very puzzling at first, and the explanation given tonight shows quite penetrating thought on the problem of making a coherent story out of them.

It would appear that certain questions were referred back to the observers during this stage of the investigation, but these questions did not elucidate one point which could have some significance. This is the fact that the observers were originally asked to imagine themselves working in the room, that is, using their hands at the benches. Whether it was subconscious or not, it may have appeared to some of these observers that, not being left-handed, the daylight was coming from the wrong direction. The high values they set for the artificial light may have been to achieve the right lighting for a right-handed person. Where this necessity was felt, it could well outweigh an aesthetic consideration of matters concerned with graduated luminosity.

Has the experiment not been complicated by arranging the view for the observers with daylight coming from a direction which favours a left-handed person?

Mr. J. Musgrove: It does not seem to have been fully realised that these buildings that Dr. Hopkinson has shown are going to be built, and although it may cost £10 or £12 to build a small scale model, it costs a great deal of money to experiment with the lighting of a full size building. Model techniques are valuable because, as architects, we want to know something about the effects of new lighting methods before incorporating them in a new building. There is another aspect, also to do with cost. I have been working on a building which is to be 10 storeys high, each floor about 10,000 sq. ft. It was planned in the first place with rooms 14 ft. 6 in. from corridor to outside wall. By cutting down corridor lengths and making rooms 24 ft. deep, we have found we can save over 1,000 sq. ft. per floor without reducing the total area of usable space. If you cost this at £5, £6 or £7 per sq. ft., it amounts to an overwhelming argument for artificial supplementary lighting.

Mr. A. G. Penny: I am glad to see once again the authors have reminded us that daylight, whilst attractive in a general sense, is not cheap and often not of the right quality at the right place and time.

I am also interested to see the revival of what is now frequently regarded as an old-fashioned method of determining proper standards of lighting.

I recall that before the war Mr. W. J. Jones and Mr. E. B. Sawyer at the Lighting Service Bureau made a survey of the standards of lighting considered desirable by a large section of the populace for the task of reading a newspaper. Their conclusions appear to be very similar to the standards now being suggested by Hopkinson and Longmore for a not dissimilar task. In this connection, I may perhaps be permitted to remark that laboratory investigations on this subject tend to be carried out through the eyes of laboratory staff who, in general, are probably rather below the average age of the community. In any case, surely standards should be set having regard to the needs of the less able members of the populace, i.e. those in the older age groups.

In the photographs and models described by the authors it appeared that the observers were judging conditions more by the study of vertical surfaces of walls than by the inspection of the horizontal pages of text books. This would suggest that they might have been equally happy if the walls had been brightened by the concentration of light on the walls, rather than on the desks. If so, this could be achieved with considerable economy of capital and running costs.

Whilst I agree that the lighting of a room could properly be changed when the usage of the room is changed, as, for instance, from a factory canteen to a dance hall, I do not think this should be automatically associated with the setting of the sun. In a factory, for instance, there is every reason for maintaining the appearance of full daylight until the end of the working day, irrespective of whether the sun sets at 3.30 p.m. or 9.30 p.m.

Dr. HOPKINSON (in reply): I cannot reply to all the discussion in the short time available to me, but Mr. Longmore and I will communicate a reply to the remaining points raised by the speakers. I welcome Prof. Voltelen's contribution very much indeed. We owe much to him and his Scandinavian colleagues for the ideas which we have developed in the paper.

There have been several comments about the validity of the technique of looking into a model building from the side and then trying to make judgments as though we were living in it. Those who work with us know of other models in which one can make appraisals, through an aperture in the floor. We believe that both methods give a good appraisal, but of course they are not a complete substitute for a full-scale mock-up—which, unfortunately, we cannot afford to have yet.

Direction of light brings in many problems which are vital to the link between architecture and lighting engineering, and which have not been solved. For example, in Scandinavian schools all the light comes from the left. In many British schools the light comes from more than one side, in American schools much of the light comes from above. Both of the rooms discussed in the paper required supplementary lighting from the top by the nature of the work which will go on in them. Where modelling is more important than quantity of light or brightness pattern, other forms of supplementary light may be desirable, even local lights as Prof. Voltelen heretically advocates.

In reply to Mr. Harris we were rather definite in the paper about levels of light. I do not want to be dogmatic about the exact levels to be chosen, but when the client has a specific lighting job to do, his advisers must be specific about what the basic level should be, and the tolerance on this level which may be permitted. As research workers knowing all the difficulties, we may feel that the answer should be hedged about with disclaimers, but these disclaimers are no help to the designer.

I think the point was brought out that the purpose of this idea of supplementary light is not to make the best of a bad daylighting job; it is in fact a new subject. We are trying to persuade the architect and lighting engineer to get together and design buildings from a new approach, and we do not want to think in terms of merely improving a poor job which never had any hope of being anything other than a poor job. I think my differences with the Americans arise from the fact that they have not in general consciously tried to wed the demands of natural and artificial good lighting. There is a great possibility of development of the concept, but not in terms of shutting out the daylight and flooding a whole interior with artificial light. We start from the assumption that daylight is necessary for human life at its best, and what we are setting out to do is to enable that daylight to be provided in the most satisfactory way in relation to the problems of modern building.

I am grateful to Mr. Stone for what he said on the economics of the permanent supplementary lighting of interiors (P.S.A.L.I., if we must have initials). There are several points of view on this. Mr. Stone has made one such point, but I think the complete answer will not be found until the buildings have gone up and we can compare what they cost with how much they might have cost.

I think the difficulty Mr. Anstey experienced is that he failed to appreciate that the scientist looks at these things in an entirely different way from the architect. The scientist has to do limited experiments and work from the particular to the general, that is, to formulate general laws from these limited experiments. We can only convince the architect we are doing something useful when the buildings go up, and he can see whether what we have done is wise or not. He asks, do we really want low ceilings? Surely the architect himself must answer that. The problem of urban conditions will not be the same as that of rural conditions. Site congestion and the need to economise on space often overrides other considerations in urban building.

I think it has been appreciated by the majority of the audience that the purpose of our paper is to open up a new subject and start a discussion. Much work remains to be done, and we hope that others, especially from the lighting industry, will take up the subject and develop it beyond the stage which our own resources permit.

The AUTHORS (communicated) : We should like to supplement Dr. Hopkinson's verbal reply by the following additional points.

Perhaps it should have been emphasised even more in the paper and in the verbal reply to Prof. Voltelen that the whole purpose of supplementary lighting is to *retain the dominance of the daylight*, both in quantity and direction. The supplementary light should be quite unobtrusive—in the experiments we made sure that the surface brightness of our laylight was below the distracting level. The coloured slides used in the demonstration could not give the impression obtained in the room, because they were viewed from a distance and so subtended a very small visual angle—consequently the ceiling laylight was much more noticeable than when one is working underneath it. A person working in the room (as opposed to a critical inspector) should be quite unaware that some of his working illumination is coming from supplementary sources. If this is taken into consideration, many of the difficulties mentioned in the discussion should disappear. The brightness pattern on the wall certainly could be improved by stopping the laylight about 3 feet short of the wall.

Mr. Harris's last point is perhaps the most important one. We do indeed want to persuade architects that this new technique is available not only for solving problems of inadequate daylight, but also to enable them to design rooms of unusual shape more suited to their purpose than rooms constrained by considerations of daylighting can ever be.

Mr. Allen very wisely brought in the economic factors which govern American practice. Mr. Musgrove gave a potent example of how PSALI can save money. The economics of the technique are not our province, however, and we are content to let the hard economic facts speak for themselves to architects and clients. Eventually we will build up a volume of case history on which generalisations can be made. Mr. Stone's studies should meanwhile be valuable in guiding us in the early stages.

In reply to Mr. Phillips and Mr. R. R. Holmes, the subjective evaluations were made on brightness and not on illumination. A laylight with black louvres might well result in a slightly different level of chosen illumination, as would a different wall brightness pattern, but we would not expect a large difference.

We have not yet been able to establish how, if at all, the supplementary light should be dimmed for night-time use. This is a matter for careful future work ; but acting on our present knowledge, we are designing for a lower level of lighting at night in the Preston school, some of the laylight lamps being switched off when the night-time lighting is switched on during a break in the class time-table (in the dark winter months). We shall not change the level while classes are sitting.

In reply to Mr. R. R. Holmes, the two sets of figures in column 4 of Table 4 are repeat judgments on that particular set of conditions (prismatic glass above 7 ft.). In reply to Mr. Anstey, no structural difficulties arise in setting the suplementary lighting into the normal depth between ceiling and floor above. No increase in this depth is therefore called for. Left- and right-handedness did not come into the judgments, as suggested by Mr. Smith. We did indeed complicate matters by asking observers to imagine themselves working in the room, but although the conflicting results caused us some disquiet, we learnt from them and so we have reported them. Mr. Penny's comments about judgments on vertical rather than horizontal surfaces are very relevant. We hope eventually to be able to erect a full-scale mock up so that judgments on more extensive criteria can be made.

Mr. Musgrove's comments came opportunely—the essential purpose of supplementary light is indeed to offer greater architectural freedom with probably, but not necessarily, a saving in building costs as well.

Lighting Codes

A meeting of the Society was held in the F.B.I. building on Wednesday, July 8, to give members an opportunity of hearing Dr. Dresler, Prof. Blackwell and Mr. Crouch speak on recent developments concerning lighting codes in Australia and the U.S.A.

In the unavoidable absence of the President the chair was taken by Mr. A. H. F. Olson, Vice-President, who briefly introduced the speakers. He said that the Society had taken advantage of their being in England, following the C.I.E. meetings at Brussels, and that they had most kindly consented to give up part of their holiday period for the benefit of I.E.S. members.

The first speaker was Dr. A. Dresler, of the Australian Department of Labour and National Service, Melbourne. He began by emphasising that the recently published Code was not an I.E.S. document but a national standard for which the Standards Association of Australia was responsible. He went on to say that its scope was confined to working interiors such as factories, workshops, offices and the like. It had been drawn up with two objects in mind, *viz.*, to make the task easy to see and to provide a good visual environment. Values of illumination were based on those given in the British I.E.S. Code, with small modifications here and there. Much attention was paid to brightness distribution in the field of view. It was assumed that the reflection factors of ceilings and the upper parts of walls would be fairly high and a minimum percentage was recommended for the upward light from fittings. This was 10 to 15 in industrial premises and 30 to 50 in offices.

The two types of glare, reflected and direct, were dealt with separately. With regard to the former, the recommendations were to avoid glossy surfaces as far as possible and to position the light sources so that their reflections in such surfaces were not visible to the worker. Sometimes it was impossible to comply with these conditions and then the downward luminance should be limited to a value related to the general level of illumination. The limit recommended, in candelas per sq. inch, was one-twelfth of the illumination in lumens per sq. foot. Here Dr. Dresler made the remark that the object of the Code was to prevent bad lighting rather than to assist in producing exceedingly good installations; that was the task of the lighting engineer.

With regard to direct glare the Code went into some detail. It contained tables of maximum values of luminance at certain downward angles and these values were related to the dimensions of the room, expressed in terms of the height of the fittings above normal eye-level. In the case of fluorescent lamps the limits were different according as the tubes were viewed sideways or end-on. No attempt was made to lay down values with a high degree of precision and in fact a division into eight classes was used, ranging from A for luminances below $\frac{1}{2}$ cd/in^2, to H for luminances between 6 and 8 cd/in^2.

In conclusion Dr. Dresler said that a number of actual lighting installations had been inspected by a panel of fifteen experienced lighting engineers and their assessment of the degree of glare had been compared with calculated values of the Harrison-Meaker glare index. It had been found than an index of 40 corresponded to an assessment of " just uncomfortable " and this had been taken as a convenient " go "/" no-go " gauge in arriving at conditions which might be regarded as at the lower limit of acceptability.

Prof. H. R. Blackwell, Director of the Institute for Research in Vision at the Ohio State University, then gave a short account of the researches he had recently conducted under the auspices of the American Illuminating Engineering Society. He began by pointing out that vision was a complex process by which the individual was enabled to gather information from his environment. It was not sufficient to specify the physical characteristics of a task; the conditions must be taken into account as well. In particular, the time taken to make the response called forth by the reception of certain information might well result in a slowing down of the rate at which information could be assimilated. It was necessary to define what was being understood by visual performance before any measurement could be made of the illumination necessary to achieve a certain rate of performance.

The first step in the research described was an extensive study of a standard task. This was the detection of a small disc of slightly different luminance from that of the extensive uniform background against which it was seen. Measurements were made of the smallest contrast detectable with 99 per cent certainty for different sizes of disc and different values of background luminance.

In order to relate the results of these experiments, carried out under ideal laboratory conditions with pre-arranged fixation, to the

performance to be expected " in the field," a second series of tests was made with a " Field Task Simulator " in which the observer was required to carry out a task similar to that used in the laboratory experiments but under conditions more like those met with in practice. In this way it was possible to find a " field factor " which could be applied to the laboratory results to allow for the difference between the ideal and normal working conditions. A series of practical performance curves could thus be derived from the curves found in the laboratory.

In order to determine the illumination needed for a particular task, an instrument called a " Visual Task Evaluator " was used. In this the actual task was reduced to visibility threshold by means of a variable contrast wedge. Then the initial contrast of a standard disc target was varied until the same reduction of contrast as that found necessary for the actual task brought this target to the threshold of visibility. In this way equivalence was established between the actual task and a certain standard task and so the illumination needed to give 99 per cent accuracy at any given rate of performance could be deduced. This process was applied to 56 tasks selected as representative of those met with in practice and the illumination needed for each was determined. For equal performance the values ranged from 1 to over 10,000 lm/ft². (These values are given in full in Prof. Blackwell's paper presented at the C.I.E. meetings in Brussels and in his more detailed paper published in *Illuminating Engineering*, Vol. 59, June, 1959.)

The application of Prof. Blackwell's work to the revision of the values of illumination recommended in the American I.E.S. Code was described by Mr. C. L. Crouch, Director of the Illuminating Engineering Research Institute, operating under the aegis of the American Society. He began by saying that it was the task of the illuminating engineer to create what he described as a " luminous environment " and to this several factors made a contribution. The amount of light reaching the work was the first of these factors and the one about which information was most readily available but there were also others which needed more study. A committee of the American I.E.S. had considered the values of illumination given in their Code and had amended these in the light of Prof. Blackwell's results. Mr. Crouch showed a number of typical examples from which it seemed clear that the new values were, in general, at least three times those recommended formerly. He then showed a number of slides of interesting recent installations with values of general illumination going up to 200 or even 400 lm/ft² and he quoted figures to show that such high values could be justified economically by increased output, fewer rejects and a reduction of absenteeism. After Mr. Crouch's impassioned advocacy of higher lighting levels there was a general discussion and the speakers answered a number of questions put to them by members present.

Mr. Imrie-Smith remarked that in Prof. Blackwell's tests the visual field was restricted to the object and its immediate surroundings. He asked whether the Visual Task Evaluator gave a truly balanced field and in reply Prof. Blackwell said that the field was 10° across which, in his opinion, was large enough.

Mr. Oliver asked Mr. Crouch how the American public reacted to high values of illumination such as 1,000 lm/ft². The reply was that after the installation of a new lighting system people were at first inclined to blame it for any visual trouble they experienced but this effect soon disappeared.

Mr. R. R. Holmes asked about the " field factor " used in arriving at the illumination values for the 56 tasks. [From the tables it appears that a factor of 10 was used for some tasks and 15 for others.]

Another speaker queried the figure of 5 " assimilations " per second in reading ; as each embraced three words on the average, this would give a reading speed of 900 words per minute. Prof. Blackwell replied that for sustained reading the number of assimilations per second was probably nearer 3 than 5.

Dr. Ballin pointed out that in the Australian Code the emphasis was on the quality factor in lighting, whereas the American Code concentrated on quantity. He felt that if the British Code emphasised quantity there was a danger that quality would suffer ; the quality aspect, even at present levels of illumination, was the more important.

Dr. Harper, Chairman of the Code Committee of the Society, described the Australian Code as a fine document. He drew attention to the distinction between Prof. Blackwell's results and their interpretation in the American Code. It was for a Code Committee to put down a set of values of illumination, and this was no easy task.

The meeting concluded with a vote of thanks to the speakers, carried by acclamation.

Light and Pattern in Painting

The Annual General Meeting of the Society, held at the National Gallery on May 12, was followed by a lecture with the above title delivered by Sir Philip Hendy, Director of the National Gallery. He began by quoting Picasso's dictum that in all painting, even abstract painting, light was the most important thing of all. The artist, he said, made use of light and shade, contrast and perspective to give a sense of depth in his picture. While in oriental art pattern was predominant, in the West it was light and shade that were all important and in fact the history of painting might almost be unfolded in terms of the artists' use of these effects.

After these introductory remarks the lecturer showed on the screen a number of pictures (all from the National Gallery collection) covering the six centuries following Duccio, who was strongly influenced by the Byzantine style and therefore had been called the last of the great artists of antiquity. The third picture shown, Masaccio's "Madonna," was remarkable for its strong and consistent light and shadow. After Ucello, stated to have been the first artist to introduce perspective, the lecturer passed on rapidly until he came to Jan van Eyck's remarkable use of light in the famous "Jan Arnolfini and his Wife." He contrasted the differing treatment of a particular subject, "The Agony in the Garden," by Giovanni Bellini and his pupil Andrea Mantegna.

Having brought his audience up to the end of the sixteenth century with Caravaggio's "Disciples at Emmaus," the lecturer turned to a painter generally recognised as a master in the use of light and shade, Rembrandt, and showed the portrait of "Saskia," a girlish figure glowing with light which was powerfully enhanced by its contrast with the subdued tones of the background. Next came some Dutch landscapes and De Hoogh's "Courtyard of a Dutch House," followed by Rubens's "Le Chapeau de Paille," with its subtle fusion of colours and its strong contrasts.

Then came a very different picture, Claude's "Embarkation of the Queen of Sheba," which has been described as one of the earliest and one of the grandest endeavours to paint the actual source of light. This work later inspired Turner to paint his "Dido building Carthage" which received very unfavourable comment from the lecturer, although an example of Turner's later style, "Rain, Steam and Speed," was extolled as a fine example of the painter's mastery of light and colour. "The Lesson," by Chardin, who brought to the humblest of subjects a loving care which made them beautiful, led naturally to Paul Cézanne's "La Vieille au Chapelet" and this closed a lecture which was received with acclamation by the large number of members of the Society present.

A vote of thanks to Sir Philip Hendy was proposed by Mr. N. Boydell and seconded by Mr. W. R. Stevens.

Additions to the List of Members

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